Greenhouse Gas Emissions Projections, Scotland

Results of Phase 1 and Phase 2 modelling

January 2024

Scottish Government
Riaghaltas na h-Alba

Customer:

Scottish Government

Customer reference:

OCEA-EA-ECC-140222

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Ricardo reference:

ED16424

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1. EXECUTIVE SUMMARY

The Scottish Government has committed to ambitious emissions reduction targets, culminating in the achievement of net zero by 2045. This is underpinned by a planning process, covering 15-year periods and refreshed on a five-yearly basis. The next Climate Change Plan, covering the period 2025-2040, will be published in draft during late 2023. In order to develop this CCP, Scottish Government requires a clear understanding of the likely baseline of emissions implied by business-as-usual activities and policies and has commissioned Ricardo AEA Ltd to carry out this assessment.

The Scottish Government presented in their "Update to the Climate Change Plan 2018 – 2032: Securing a Green Recovery on a Path to Net Zero, 16 Dec 2020" (referred to hereafter as Climate Change Plan Update, or CCPu)[1] a pathway to their new and ambitious targets set by the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019.[2] The required outcome of the CCPu is to deliver Scotland's yearly climate change targets (and ultimately contribute to the net zero by 2045 target).

The project aimed to:

- Provide projections of emissions sources under a business-as-usual scenario for each year from 2019 through to 2045.
- Quantify the impacts at this point in time of policies in place by providing a set of greenhouse gas (GHG) projections that considers quantifiable mitigation actions laid out in the CCPu.
- Generate estimates of the emissions reductions that result from each of the policy outcomes as set out in the CCPu and policy papers published since.
- Base projections on a bottom-up aggregation.

The emissions projections will be an important component in subsequent work by Scottish Government to identify the level of abatement required in the next Climate Change Plan.

The sectors modelled were Agriculture, Buildings, Electricity, Industry, Transport, Waste, Negative Emission Technologies (NETs), and Land Use, Land-Use Change and Forestry (LULUCF).

A range of scenarios were modelled, including high and low economic growth scenarios, and high and low hydrogen scenarios. This executive summary focuses on the central scenario; in this scenario, economic growth assumptions are the same as in the baseline scenario, but the CCPu policies and proposals for each sector serve to mitigate GHG emissions.

[1] Scottish Government, '*Update to the Climate Change Plan 2018 – 2032: Securing a Green Recovery on a Path to Net Zero'* (16 Dec 2020). Available at: https://www.gov.scot/publications/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/

[2] Climate Change (Emissions Reduction Targets) (Scotland) Act 2019. Available at: https://www.legislation.gov.uk/asp/2019/15

There have been two Phases to the work:

- Phase 1 estimated a trajectory of GHG emissions delivered by the CCPu policy package and including subsequent policy publications. This phase captured the possible impact of the policies as written at the time of publication.
- Phase 2 allowed for further refinements to the modelling, and notably introduced higher levels of ambition for some sectors, based on the intended "Outcomes" set out in the CCPu.

Presented below are the results from the Phase 1 and Phase 2 modelling, focusing on the “Central” scenario. The modelling assumptions, policy impacts, uncertainties and sensitivities for each sector are discussed in more detail in subsequent chapters.

Note that the LULUCF sector took a different approach to the other sectors, which is discussed further in Section 11.

Phase 1 results – Central scenario

Figure 1-1: Total emissions (kt CO2e) split by sector for the Central scenario of the Phase 1 modelling shows total GHG emissions and sectoral contributions throughout the projection period for the central scenario of the Phase 1 modelling. Table 1-1 shows the results of the Phase 1 modelling (i.e., of policies assessed during the study) for the central scenario (including the LULUCF sector) for key years. Note that 2032 is included as a key year as this is the end-year for the CCPu.

Figure 1-1: Total emissions (kt CO_2e) split by sector for the Central scenario of the Phase 1 modelling

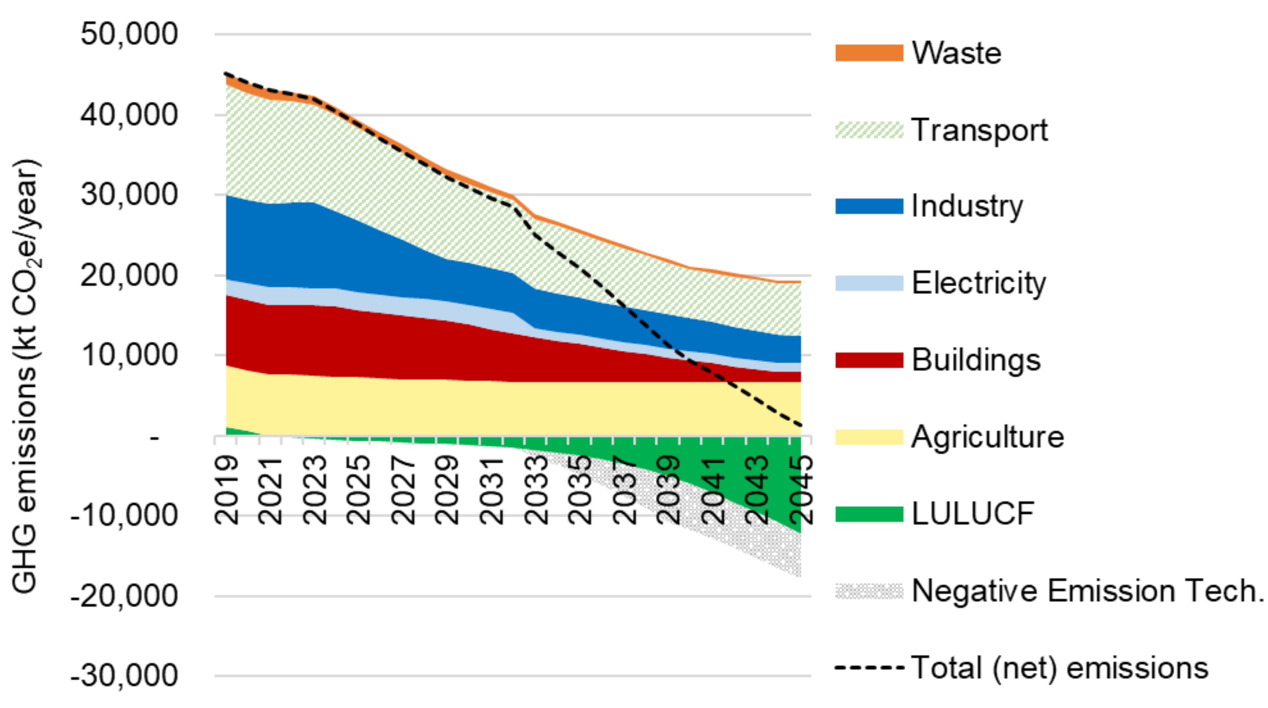


Table 1-1. Emissions reductions for the central scenario (including LULUCF) under the Phase 1 modelling

	2025	2030	2032	2035	2040	2045	2050
Emissions reduction from baseline (kt CO_2e)	5,763	13,887	16,781	24,981	37,371	46,224	52,923
Percentage reduction from baseline	13%	31%	37%	55%	80%	97%	111%

Key take-home points from this analysis are that:

- The biggest emissions reductions are from the Buildings and Transport sectors. Emissions reductions in these sectors are primarily associated with the phase-down of fossil fuel use in favour of electrically powered technologies or other zero emission alternatives. In both cases, this type of "fuel switching" has a larger GHG emissions impact than measures aimed at energy demand reduction such as increasing sustainable travel modes or retrofitting buildings. However, such measures should still be seen as important as they help to minimise demands on grid infrastructure, avoid indirect emissions from vehicle manufacture, reduce people's energy bills, and so on.
- Industrial sector decarbonisation is assumed to proceed in line with the requirements of the UK Emissions Trading Scheme (ETS). This is the key policy driving GHG reductions in the industrial sector; the majority of the other CCPu proposals were considered not to have a quantifiable impact on emissions although they would act as supporting measures that could facilitate decarbonisation.
- The results show "negative emissions" from the LULUCF sector, as peatland restoration and afforestation would increasingly act as a carbon sink, along with NETs. However, in both cases the results should be interpreted with great caution.[3] The complexity of the LULUCF sector contributes to relatively high uncertainty in the net emissions from this sector, as all sources and sinks are based on computer models rather than direct measurement. The central scenario modelled for LULUCF is based on ambitious peatland restoration rates, but the feasibility of this scenario is unclear. In the case of NETs, we have modelled the sector reaching the quantitative targets set out in the CCPu. However, the sector is in its infancy and the specific proposals in the CCPu would not necessarily guarantee this level of deployment. If one excludes the LULUCF and NETs from the analysis, GHG emissions in 2045 would be close to 20 $MtCO_2e$.

[3] The LULUCF sector was modelled using a sector specific model that required a large offset to be applied to its output from 2021 onwards to remove an inconsistency between its output and the historical time series data obtained from the 2022 Devolved Administration Inventory. Although theoretically, the output from this work including LULUCF suggests net zero could be achieved by 2050, caution is advised due to the adjustments made to integrate the LULUCF sector into our work. To achieve a higher degree of accuracy and lower uncertainty in the LULUCF sector projections, Scottish Government would need to use the CARBINE model to re-model projections in this sector. This was not possible within the time-frame and resources of this work.

- The Agriculture sector shows a relatively small reduction in emissions which, in this analysis, is driven by the Agricultural Transformation Programme. Most of the other policies relating to the Agriculture sector do not have quantifiable GHG emissions impacts, either because they are considered supporting measures or due to lack of data.
- For the Waste sector, reducing the amount of biodegradable waste sent to landfill is considered the main driver of GHG emissions reductions. The target of reducing food waste would contribute towards further reductions. Waste is a complicated sector and there were some measures, such as the aim of establishing a more circular economy, which hold the potential to reduce net emissions globally but where it was not possible to provide a quantitative, sector-based estimate within the scope of this project.
- Electrification, which is key to reducing emissions from the Buildings, Transport and Industry sectors in particular, will rely on access to a secure, reliable source of renewable electricity. The Electricity sector policies in the CCPu can therefore be said to reduce emissions from multiple sectors indirectly, inasmuch as they minimise the need to generate electricity using unabated fossil fuels. The largest impacts in this sector that have been assessed in this study are associated with (a) to the Peterhead gas power station being decommissioned and replaced with a carbon capture, storage and utilisation (CCS) gas power station and (b) additional offshore wind capacity.

The results of this analysis show Scotland coming very close to its net zero target by 2045, and achieving net negative emissions by 2050. However, bearing in mind the uncertainty around the LULUCF estimates and deployment of NETs in particular, **there is a very high risk that the Scottish Government's statutory targets will not be achieved through reliance on action covered by Phase 1 and without additional policies**.

As shown above, without the GHG reductions from the LULUCF and NETs, there could be a gap of close to 20 $MtCO_2e$ by 2045 between actual emissions and the target level without additional policies. That may still be an optimistic assessment given the lack of a defined regulatory approach for some important mitigation measures, such as phasing out fossil fuel heating in buildings.

Action by the UK government on reserved areas also supports Scottish decarbonisation, with – for example – regulations being implemented around the phase out of ICE vehicles. These are expected to play a key role; the UK ETS (and its supporting measures) is estimated in this study to provide reductions of 6,013 kt CO_2e in 2032 (see

Table 7-8). Nonetheless, the results of Phase 1 highlight the need for further action.

The Scottish Government is considering new policies as part of the development of the next Climate Change Plan and the ongoing implementation and development of strategies, plans and policies at a sector level.

Phase 2 results – Central scenario

Figure 1-2 shows total GHG emissions and sectoral contributions throughout the projection period for the central scenario of the Phase 1 modelling. Table 1-2 shows the results of the Phase 2 modelling (i.e., of policies) for the central scenario (including the LULUCF sector) for key years.

Figure 1-2: Total emissions (kt CO_2e) split by sector for the Central scenario of the Phase 2 modelling

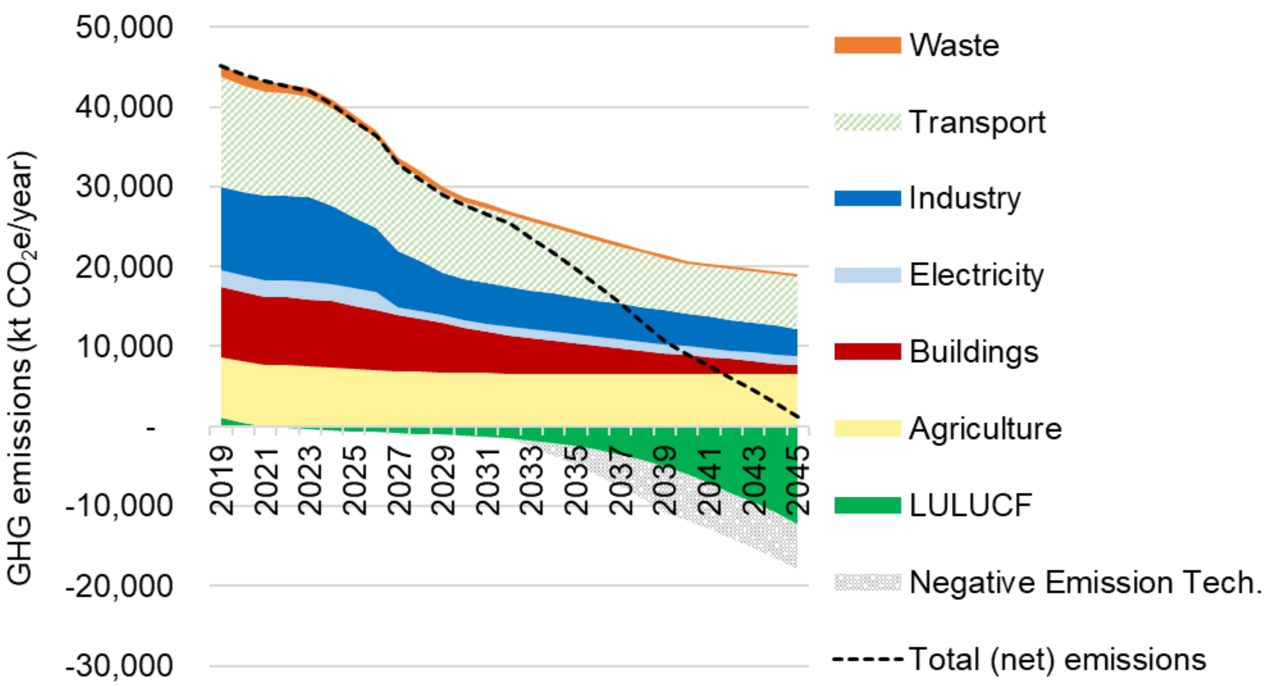


Table 1-2. Emissions reductions for the central scenario (including LULUCF) under the Phase 2 modelling

	2025	2030	2032	2035	2040	2045	2050
Emissions reduction from baseline (kt CO_2e)	6,176	17,146	19,767	26,122	37,781	46,397	53,096
Percentage reduction from baseline	14%	38%	44%	57%	81%	98%	111%

Net GHG emissions in 2045 are calculated to be slightly lower in Phase 2 than Phase 1, although both phases were calculated to achieve a similar overall reduction in emissions of

c. 97-98%. As stated previously, these figures should be interpreted with great caution due to uncertainties in all sectors, but especially regarding LULUCF and NETs.

The difference in Phase 2 is due to small additional GHG reductions occurring in the Agriculture, Buildings and Transport sectors:

- In Agriculture the difference is due to assessing outcomes rather than a difference in the overall level of ambition.
- In Buildings the difference is due to changes in the targets that were modelled for non-domestic buildings; in Phase 1 this was based on decarbonising a certain number of buildings whereas in Phase 2 the targets related to overall fossil fuel consumption.
- In Transport the difference is primarily due to greater reductions in private vehicle use.

No further reductions in Phase 2 are seen in the NETs, Industry, and Waste sectors as no further impacts were modelled in these sectors – this is because no further quantifiable targets were identified through discussions with Scottish Government in these sectors at the time of writing. In some cases, there was a change in the cumulative emissions for certain sectors, due to the adoption of stronger policy ambition or changes in the timing of measures. For example, for the Electricity sector, 2045 emissions are the same between Phase 1 and Phase 2, but Phase 2 sees emissions reduce to their final level much earlier due to the change in presumed timing of CCS at Peterhead. Further details of the modelling methodology for each sector, including differences between Phases 1 and 2, are provided in subsequent chapters of this report.

The most important take-home points of the Phase 2 analysis are similar to those described for Phase 1 (see above). The Phase 2 modelling also highlights the potential to achieve lower cumulative emissions though adoption of stronger policy ambition and/or bringing forward key policy interventions.

Conclusions

The modelling results of this study show GHG emissions getting close to net zero by 2045. However, when interpreting these results it is important to account for uncertainties in the modelling work, and the lack of specific delivery mechanisms for many of the CCPu proposals.

In many cases, policies and proposals in the CCPu are expressed as high-level targets where the regulatory approach, timing, funding sources, and so on have not yet been confirmed. For example, in the NETs sector, we were able to model the impact of deployment targets because these are expressed quantitatively. But the commitments in the CCPu (e.g. “Support the development of NETs technologies within Scotland”) are non-specific – there is no clear pathway towards delivering the targets for NETs. Similar examples exist for other sectors. On that basis, this study indicates that the policies and outcomes set out in the CCPu need to be built on to meet annual emissions envelopes and targets set out under the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019.

It is typical for governments to adopt different approaches, ranging from direct action to indirect influence and awareness-raising, to try and achieve GHG reductions. So, not all the Scottish Government’s policies and proposals need to result in quantifiable emissions reductions in order to provide an environmental benefit. However, for proposals that do require a quantitative assessment, it is recommended that these should be:

- linked to quantitative targets or metrics;
- backed up by specific policy proposals; and
- confirmed through allocation of funding, relevant legislation, etc.

This would give greater confidence that the GHG reductions can be achieved.

2. Introduction

2.1 Background

The Climate Change Act 2019 set ambitious targets that would require Scotland to achieve a 75% reduction in greenhouse gas (GHG) emissions[4] by 2030 and net zero GHG emissions by 2045. In the Climate Change Plan Update (CCPu), published in December 2020, the Scottish Government described the actions that it proposes to take in order to help ensure that these targets are met.

The CCPu presented "emissions envelopes", which reflect the decarbonisation pathway that each sector would need to achieve in order for the economy as a whole to be on track to reach net zero. The sectoral envelopes collectively add up to the total annual emissions reductions that are required. For each sector in the CCPu, the Scottish Government then defined a range of outcomes which, if achieved, are intended to enable each sector to meet the emissions envelopes. Each outcome is supported by a set of policies that the Scottish Government is proposing to help deliver GHG emissions reductions.

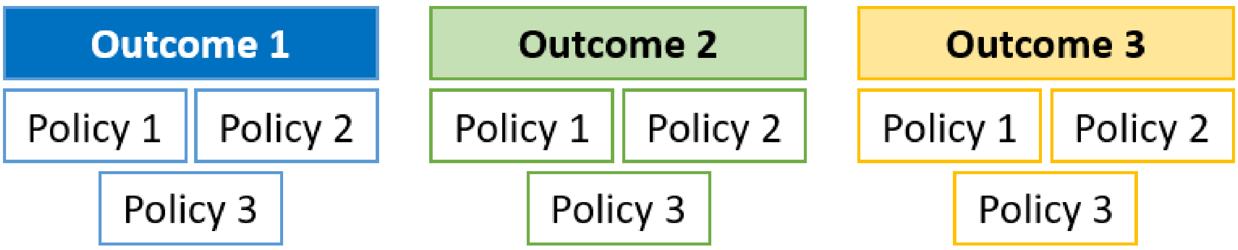
The difference between policies and outcomes is illustrated in Box 1 below.

Box 1: Policies (Phase 1) vs Outcomes (Phase 2) of the CCPu

The Policies of the CCPu are the specific measures the Scottish Government intend to take to reduce GHG emissions. The Outcomes of the CCPu are essentially targets or overarching ambitions that the Scottish Government hopes to achieve.

The Policies are designed with the intention of supporting the achievement of the Outcomes, as shown below. However, the Outcomes may be considered aspirational to a certain extent – as they may not yet have sufficient policy mechanisms to be achieved.

Each suite of Policies is designed to achieve an intended Outcome



The Scottish Government had previously undertaken modelling work to establish a net zero pathway for the Scottish economy, using the Scottish TIMES model, which was used to inform the CCPu. While the TIMES model has a large amount of detail on specific mitigation technologies, it was not designed to assess the impact of the individual policies. Hence a bottom-up assessment of the individual policies was needed alongside the TIMES modelling, to understand the expected contribution of these policies on Scotland's net zero target.

[4] Relative to a 1990 baseline.

The aim of this research was to produce a yearly estimate of Scotland's business-as-usual or "baseline" greenhouse gas (GHG) emissions from 2019 up to the Scottish Government's targeted net zero date of 2045, and then quantify the impacts of the policies in place under a set of alternative future GHG emissions scenarios. These will be used as an evidence base for future climate change planning within the Scottish Government.

There have been two "phases" to the work, representing two main iterations of the GHG emissions modelling. Phase 1 delivered an initial set of GHG projections, estimating the impacts of the quantifiable policies in the CCPu. That analysis showed that the existing policies in the CCPu are not sufficient for all the intended Outcomes to be achieved. A second iteration of the work (Phase 2) was subsequently carried out, which allowed for further refinements to the modelling, and notably introduced higher levels of ambition for some sectors. In effect, Phase 2 explored what would happen to GHG emissions if the intended outcomes set out in the CCPu were achieved, regardless of whether there are currently enough policies to deliver them.

2.2 Scope of the work

The scope of the work was to:

- Provide projections of sources of emissions and removals of CO_2 in a business-as-usual case for each year from 2019 through to 2045.
- Quantify the impacts of policies in place by providing a set of GHG projections, considering the quantifiable policies of the CCPu.
- Base projections on a bottom-up aggregation of the following sets of information:
    - Estimates of the impacts on Scottish source emissions of relevant Scottish Government policies, in particular those in the Climate Change Plan Update (CCPu);
    - Estimates of the impacts on Scottish source emissions of key UK Government policies;
    - Other significant underlying drivers of emissions (demographic, social, economic) where there is reliable evidence from which to infer long run trends.
- Generate estimates of the emissions reductions that result from each of the policy outcomes as set out in the CCPu and policy papers published since.

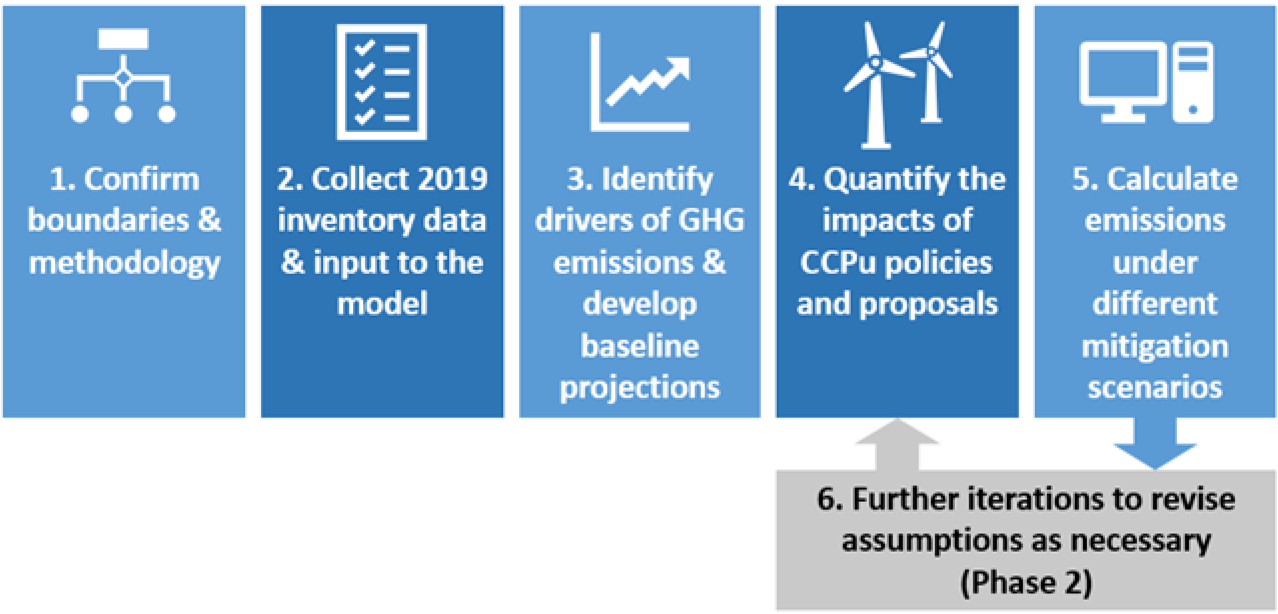
The projections are provided for Scotland as a whole and for each of the eight sectors as specified in the recent Climate Change Plan Update – Electricity, Buildings, Transport, Industry, Waste, Land Use Land Use Change and Forestry (LULUCF), Agriculture and Negative Emissions Technologies – and each of their subsectors. The investigation into the LULUCF sector took a slightly different approach to the other sectors (using a sector-specific model), and so is covered separately in Appendix 1.

The projections of emissions and removals consider a range of sensitivities to provide a central case and a reasonable high and low emissions case.

3. Methodology

3.1 Overview of approach

Our approach to delivering the GHG emissions projections is summarised in the diagram below.



Step 1: The boundaries of the analysis and methodology were agreed at project inception. This included an initial screening exercise to establish which CCPu policies would be taken forward for assessment. Ricardo sector experts engaged with representatives of the Scottish Government to identify existing impact assessments for CCPu policies and, for those without an impact assessment, discuss how the GHG impacts could be quantified within the scope of this project.

Step 2: The next step was to collect inventory data and input this to the GHG projections model developed by Ricardo.

The GHG projections set out in this report use 2019 as the starting point or “base year”. The source of this data was the Devolved Administration GHG inventory, which was published in 2022. The data in this publication is two years in arrears, so the most recent data it contained was for 2020. However, due to impacts of COVID-19 on the economy, the 2020 data was considered anomalous, and therefore the year 2019 was selected as the base year This approach meant that the starting year and baseline projection are consistent with historical trends in the inventory.

Step 3: From 2019 onwards, a baseline projection was then calculated. This is essentially a ‘business as usual’ scenario where trends continue without the influence of any mitigation policies. In the baseline scenario, the main drivers of change are associated with economic and population growth.

- Estimates of economic growth are based on projections for gross value added (GVA) as per Office of National Statistics (ONS) data on regional GVA.[5]
- Estimates of population growth are based on National Records of Scotland (NRS) population projections.[6]

In some sectors, energy use and emissions are assumed to scale directly with these trends. For instance, industrial emissions are assumed to scale with economic growth and domestic wastewater emissions are assumed to scale with population. In other sectors, the relationship is less direct, and/or there may be additional underlying drivers of energy use and emissions that were chosen for modelling in agreement with the Scottish Government. These are summarised in the table below. Further information on the sector-specific drivers is provided in subsequent chapters.

[5] ONS, *'Regional Gross Value Added (GVA)'* (2021). Available at: https://www.ons.gov.uk/economy/grossvalueaddedgva

[6] National Records of Scotland, *'Population Estimates'* (2021). Available at: https://www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/population/population-estimates

Table 3-1. Underlying drivers of energy use and emissions in the Baseline scenario

Sector	Underlying drivers of energy use and emissions in the Baseline scenario
Agriculture	Changes are based on straight line projections for livestock numbers and fertiliser use.
Buildings	Energy use in residential buildings is assumed to increase with new construction. The number of new dwellings is based on projected changes in population growth and number of households. Energy use in non-residential buildings is assumed to scale with economic growth (GVA).
Electricity	The main driver of emissions in this sector is the mix of technologies used for electricity generation in Scotland; the baseline scenario accounted for additional renewables that have been granted planning permission.
Industry	Emissions are assumed to scale with economic growth (GVA).
Transport	The baseline accounted for projected changes in: • Traffic (measured in vehicle-kilometres) • Energy efficiency of vehicles • Uptake of ultra-low emission vehicles (ULEVs) • Aircraft movements • Freight demand (measured in tonnes)
Waste	The baseline accounted for projected changes in the amount of waste generated and how it is treated (recycling, composting, landfill, and so on). Domestic wastewater emissions were assumed to scale with population growth. Industrial wastewater emissions were assumed to scale with economic growth.
Negative Emission Technologies (NETs)	N/a - In the baseline scenario, it was assumed that there would be no change in deployment of NETs.
Land use, land use change and forestry (LULUCF)	The main focus of emission projections in this sector were afforestation and peatland restoration. [Note, the work on this sector was completed by UK CEH using a sector-specific model. The methodological approach to the work was very different to that taken in the other sectors of the work. Details of the work are provided in Appendix 1.]

The baseline, and all other future GHG pathways, were modelled using the Ricardo Net Zero Projections (NZP) tool, which enables users to model the impact of implementing mitigation measures on GHG emissions over time.

What is the NZP tool?

The tool is designed to enable the development of scenarios for reaching net zero by any given target year and allows the users to define mitigation measures for each line (sector, sub-sector, fuel type or source of emissions) in the GHG emissions inventory.

These scenarios can be used to build a baseline projection, assess the likely impact of planned measures, and model the impact of alternative strategies to reaching net zero ("scenarios"). The tool can also be used to undertake sensitivity testing around the impact of changes in assumptions.

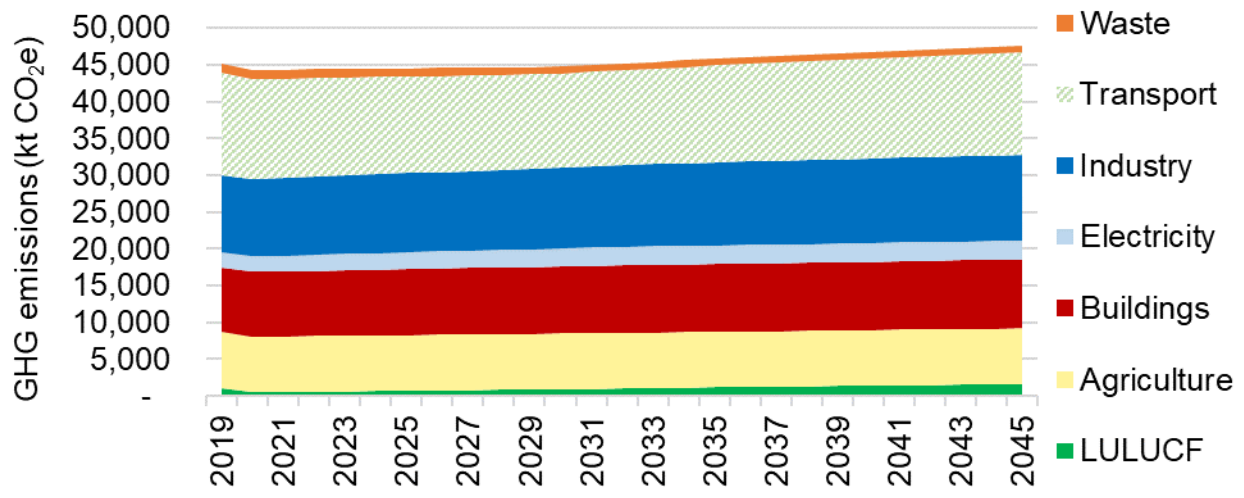
GHG reductions from the mitigation measures in each sector and sub-sector were initially modelled separately, and then combined into a single model to ensure that interactions between sectors were accounted for.

Note the following:

- Modelling for the LULUCF sector was undertaken separately by CEH, and the results were integrated into the Ricardo NZP tool once they were finalised.
- We modelled electricity demand in each sector/sub-sector and then confirmed that the amount of electricity generated in Scotland would always exceed this demand, so there was no need to model imports of electricity.

Emissions in the baseline scenario are shown in the figure below. Overall, it is expected that there would be a relatively small (c. 5%) increase in total emissions between 2019 and 2045.

Figure 3-1. Total emissions under the baseline scenario, split by sector



Step 4: Next, the impacts of CCPu policies and proposals were assessed by sector experts from Ricardo and CEH. The precise methodology that was used to quantify emissions reductions from each policy/proposal depended on whether the policy had already undergone a full impact assessment, and if not, what level of data was available to support such an assessment. Further information on the approach taken for each sector is provided in subsequent chapters of this report.

When assessing the impacts of CCPu policies/outcomes, a wide range of variables were considered, including: improvements in energy efficiency, fuel switching, product substitutions and phase outs, changes in transport modes, reductions in demand, material usage and waste production, increased digitisation, electrification, carbon capture & storage and negative emissions technologies (NETs).

For the purpose of this assessment, some policies have been grouped into “packages”. A “package” refers to a collection of policies where the combined impact of the policies has been quantified, but disaggregated results are not provided.

This approach was adopted for the following reasons:

- In some cases, different policies are aimed at tackling similar issues. Where they overlap, there would be a risk of double-counting if the policies were quantified separately. For example, the Scottish Government has a variety of funding schemes in place to promote uptake of zero direct emission heating (ZDEH) systems. Separately, there is an ambition for all buildings to switch to ZDEH. The former would contribute towards the latter; therefore, it makes more sense to assess the policies in combination.
- Some policies and proposals essentially serve as “supporting measures”, where there is no quantifiable target or outcome even if they still help to achieve the Scottish Government’s goals. An example would be requiring Local Authorities to produce Local Heat and Energy Efficiency Strategies (LHEES). These would facilitate the deployment of solutions such as heat networks but would not directly result in GHG emissions reductions. Policies that were deemed unquantifiable have either been screened out of the assessment or included in packages as “supporting measures”.

In this context, one of the benefits of modelling policies in groups is that it helps to reduce the level of uncertainty relative to trying to estimate the impacts of individual policies and then trying to correct for the interactions between them.

Step 5: Having established the baseline projection, and then calculated the impacts of CCPu policies/proposals, the work explored five additional future GHG emissions scenarios. In these scenarios, the Scottish Government’s policies and proposals on climate change, as set out in the CCPu, act as mitigation measures that reduce GHG emissions. The scenarios reflect different assumptions on drivers and structural changes, and thus often assume different rates of action implementation.

A summary of each scenario is provided below, and further details on how this has been reflected in the modelling for each sector is provided in subsequent chapters.

Table 3-2. Scenarios modelled

Scenario	Description
A central economic growth scenario	Economic growth assumptions are the same as in the baseline scenario, but the CCPu policies and proposals for each sector serve to mitigate GHG emissions.
A high economic growth scenario	Increased economic activity is assumed to result in higher emissions from industry and non-residential buildings, as well as increased travel demand, when compared against the central scenario. This would tend to increase emissions. However, this is counteracted by the fact that higher economic growth could accelerate uptake of GHG reduction measures, such as ULEVs and energy efficiency in buildings. It could also lead to more capital funding becoming available to support GHG reduction initiatives. Greater deployment of NETs would be required to offset the increase in emissions.
A low economic growth scenario	The assumptions in the high economic growth scenario (see above) are reversed, such that there is generally lower demand for energy and transport, but also lower uptake of GHG reduction measures.
A high hydrogen availability scenario	In this scenario, there is a greater shift towards the use of hydrogen in the Industrial sector. Some hydrogen is also blended into the gas grid to heat buildings as an interim measure prior to the adoption of zero direct emission heating systems (ZDEH) – although note that this was only modelled in Phase 2 of the work (see below for an explanation of the “Phases”). It is also assumed that there would be higher growth in NETs since more BECCS would be needed to produce the hydrogen.
A low hydrogen availability scenario	In this scenario, there is a greater shift towards electrification rather than hydrogen in the Industrial sector. It is also assumed that there would be lower growth in NETs since less BECCS would be needed to produce the hydrogen.

Note: Hydrogen scenarios were only modelled for Buildings, Industry and NETs as these were the only sectors where future hydrogen availability was considered likely to have a significant on sector development and sectoral emissions.

Step 6: After the initial set of GHG projections were developed, in what will henceforth be referred to as Phase 1 of the project, a second iteration was carried out, which will be referred to as Phase 2. Phase 2 allowed for further refinements to the modelling, and notably introduced higher levels of ambition for some sectors, based on the intended outcomes set out in the CCPu.

In Phase 2 of the work, details of the updated modelling approach were agreed with the Scottish Government in a series of sectoral workshops. The workshops looked beyond the specific policies in the CCPu by considering approaches outlined in more recent policy papers, sector road maps and any relevant research and analysis of additional policy measures which the Scottish Government sector teams shared with Ricardo sector experts. Once the modelling assumptions were agreed, the GHG projections from Phase 1 were updated to provide a revised set of results.

As a shorthand for differentiating between them, Phase 1 may be considered the “Policies” phase while Phase 2 was the “Outcomes” phase – though for many sectors, Phase 2 only involved modelling refinements, as detailed in Table 3-3 below.

Further details on the changes modelled in each sector are provided in subsequent chapters.

Table 3-3a. Differences between Phase 1 and Phase 2 modelling for Agriculture, Buildings, Electricity, Industry.

Sector	Is there a difference between P1 / P2?	Description of additional modelling that was carried out in Phase 2
Agriculture	Yes	Phase 2 consisted of modelling of outcomes, which included updates to the modelling assumptions (e.g., improved uptake estimates for better nitrogen use) rather than a change in the overall level of ambition.
Buildings	Yes	In Phase 1, we modelled the impacts of EPC upgrades to domestic buildings, and the proposed Heat in Buildings Regulation which would see all buildings switch to zero direct emission heating (ZDEH), alongside specific initiatives such as the Energy Company Obligation, smart meter installations, HiBS domestic and SME Delivery Schemes and the Scottish Green Public Sector Estate Scheme. In Phase 2, we modelled EPC upgrades to domestic buildings, reducing service sector fossil fuel demand to 5,000 GWh per year, and the entire building stock transitioning to ZDEH. Initiatives such as the HiBS domestic and SME Delivery Schemes were assumed to contribute to those outcomes so were not modelled separately. Also in Phase 2, the 'High Hydrogen' scenario explored the impact of blending up to 20% green hydrogen into the gas network by as an interim measure prior to the wider adoption of electrically powered ZDEH.
Electricity	Yes	In Phase 2 the following changes were made: • Timing of CCS at Peterhead • Average load factors for renewable technologies
Industry	No	Some modelling changes were adopted, but these were applied retroactively to the Phase 1 modelling as well, so there is no difference in results for Phase 1 and Phase 2

Table 3-4b. Differences between Phase 1 and Phase 2 modelling for Transport, Waste, METS, LULUCF.

Sector	Is there a difference between P1 / P2?	Description of additional modelling that was carried out in Phase 2
Transport	Yes	In Phase 2 the following changes were made: • Greater reduction in car-kilometres (20% in Phase 2 as opposed to 10% in Phase 1) • Additional time steps were added to the model to refine the assumptions about phasing out internal combustion engine (ICE) vehicles • Full decarbonisation of domestic flights within Scotland by 2040 was modelled in Phase 2 whereas in Phase 1 this was limited to uptake of sustainable aviation fuel (SAF)
Waste	No	No additional modelling was carried out for Phase 2 of this work, as no further quantifiable policies/targets could be identified.
NETs	No	No additional modelling was carried out for Phase 2 of this work, as no further quantifiable policies/targets could be identified.
LULUCF	No	No additional modelling was carried out for Phase 2 of this work, as no further quantifiable policies/targets could be identified.

The baseline projection is consistent between the two Phases.

It is important to note that some outcomes are not supported by enough specific policies or proposals in the CCPu to enable them to be achieved. Some of the policies or proposals that have already been published are nonetheless at an early stage of development where the regulatory approach, funding, etc. has not yet been confirmed. The impact on GHG emissions will depend on the specific technologies and solutions that are ultimately adopted. **All of the quantified GHG impacts set out in this report are therefore subject to confirmation of the regulatory approach or policy design.**

3.2 Comparison against the Scottish TIMES model

The table below briefly compares the modelling approaches used in the Scottish TIMES model and the bottom-up modelling approach used in this study delivered by the Ricardo Net Zero Gap Analysis Tool. This comparison provides an insight into the potential differences and comparability of outputs between the two modelling approaches, and the key limitations of each modelling approach.

Table 3-5. Strengths and limitations of the Ricardo Net Zero Gap Analysis Tool

Topic	Scottish TIMES Model	Ricardo Net Zero Gap Analysis Tool
Strengths	Produces a cost-optimised net zero pathway based on the availability and relative cost effectiveness of technology-based mitigation measures. Adopts a whole system approach to optimisation, which is particularly useful when modelling energy transformations.	Produces an annual bottom-up estimate of policy impacts that is grounded in market realism and reflects views stakeholders as captured in sector roadmaps and research. Highly adaptable – can model wide range of mitigation measures at high or detailed level. Short run times, with low data requirements.
Weaknesses	Assumes perfect market in which all cost- effective technologies are taken up by users and no supply chain limitations (other than those built into the model through construction times, asset lifetimes, exogenous constraints, etc). Data gathering can take several years as require comprehensive data on economy and mitigation measures. Long run times.	"Optimisation" is done off model by modeller via a stakeholder consultation exercise (known as "back casting"). Non-linear market dynamics and sector interactions are linearised to reduce data input requirements. Additional detail can be added by modelling policy implementation in phase, for example. However in practice, the level of technical detail is usually limited by stakeholder knowledge and budget.
Limitations	Pathway optimisation is done at a whole economy level with outputs generated every 5 years to reduce model run times. Energy & materials flows across system boundaries are fixed to limit complexity.	Pathway optimisation is done using scenarios that may be based on unrealistic expectations and conservative estimates. Energy & materials flows across system boundaries are fixed to limit complexity.
Options	Deployment of specific technologies can be constrained by the user through resource constraints or technology and resource costs, or by increasing the resolution of technology supply curves.	Can be used to support an open and transparent discussion with stakeholders on expectations, and policy & technology gaps. More technical detail can be added to support decisions, including cost analysis.

Further information on the limitations, uncertainties and sensitivities that apply to each sector are provided in subsequent chapters.

4. Agriculture sector

4.1 Sector Overview

4.1.1 Sector Background

The Agriculture sector is a complex, diverse sector employing around 67,000 people in Scotland and covering nearly 80% of Scotland's land mass. In 2018, the total income from farming was £672m[7], with agriculture contributing 0.8% to the gross value added (GVA) at basic prices. In 2020, agriculture contributes 18%[8] of Scotland's total greenhouse gas emissions with significant emissions of CH_4 and N_2O, some emissions of CO_2 and removals of CO_2 by sinks. There are strong linkages with the LULUCF and energy sectors through inter-related needs from the land, such as forestry, peatland restoration, biodiversity creation, growing biomass for energy generation, food and alcohol production and recreation.

Unlike other sectors, non-CO_2 GHG emissions are a major share of GHG emissions. These non-CO_2 emissions are mainly N_2O emitted from soil following the application of fertiliser and manures, and emissions of CH_4 produced from enteric fermentation and manure management.

4.1.2 Subsectors Considered

The subsectors modelled are based on the subsectors of the GHG inventory for agriculture. The subsectors are listed below with some notes on the inclusions in each.

- Livestock
    - Includes enteric fermentation from dairy and non-dairy cattle, sheep, pigs and other livestock; emissions from management of manure, but not including soil emissions after manure application to land.
- Crops, including:
    - emissions following application of inorganic N (nitrogen) fertilisers, animal manure and sewage sludge to soils,
    - direct emissions from digestate,
    - emissions from pasture grazed by livestock,
    - emissions from crop residues,
    - emissions following mineralisation associated with loss/gain of soil organic matter,
    - emissions following cultivation of organic soils,
    - emissions following atmospheric deposition and nitrogen leaching and run-off,
    - emissions from liming and urea application
    - emissions from field burning are accounted for in this category but are assumed to not occur in Scotland.

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[7] Scottish Government, *'Agriculture Facts and Figures'* (2019). Available at: https://www.gov.scot/binaries/content/documents/govscot/publications/statistics/2019/06/agriculture-facts-figures-2019/documents/agriculture-facts-figures-2019/agriculture-facts-figures-2019/govscot%3Adocument/agriculture-facts-figures-2019.pdf

[8] NAEI, *'Devolved Administration GHG Inventory 1990-2020'* (2022). Available at: https://naei.beis.gov.uk/reports/reports?section_id=3

- Other agriculture
    - Fuel combustion and other energy use. This is 10% of emissions from agriculture.

4.1.3 Data Sources

The main data sources used to undertake the assessment of the Agriculture sector are detailed below.

Table 4-1. A summary of the different data sources used in the assessment of the Agriculture sector

Purpose	Data used	Comment
GHG inventory for Scotland	UK National Atmospheric Emissions Inventory (UK NAEI)	GHG inventory for Scotland needed to estimate impacts of policies on emissions.
Agricultural activity projections	The main activity data sources were: - British practice survey for N use trends in Scotland - June census data for livestock	We used these data sources to estimate projected trends in both animal numbers and N use

4.1.4 Underlying Drivers of Energy & Emissions

For agricultural emissions, the main underlying drivers are livestock numbers and fertiliser use. We looked at past trends and created a rolling average over 3 years to create a future trend for each of the livestock types. There were differences between the livestock types with growth in camelids and deer, for example, but the total numbers of these were small in comparison to sheep and cattle numbers, and therefore trivial in terms of GHG emissions.

For fertiliser use data, the trends do not include the impact of war in Ukraine or recent high fertiliser prices, as values were available only up to 2019.

4.2 Policy Measures and Outcomes Modelled

4.2.1 Phase 1 – Policy Measures

All the Agriculture sector policies for which we could identify quantifiable evidence for impacts on agricultural practices and emissions (or supporting a policy for which this could be identified) were grouped into a package (A1). The other policies were deemed unquantifiable (and also not supporting a quantifiable policy), as baseline emissions could not be determined, and/or they contained no tangible targets. The policies and proposals in the package A1 are given in Table 4-2.

For the assessment of Outcome 1, Policy 1 (see Table 4-2) which refers directly to the Agricultural Transformation Programme, we used a report by SAC consulting[9] on the GHG savings attributed to the capital investments resulting from the Agricultural Transformation Programme piloted from autumn 2020. We used the estimated value of 6% emissions savings for this pilot programme. The report estimates this only for beef farming as this is the only sector they had a baseline for, but we believe similar savings could be found in the dairy industry as it covers similar manure management and animal welfare techniques. Better manure management also has the potential to reduce inorganic fertiliser use in the arable sector.

The other policies and proposals (such as training and advice) that we included in package A1 support the intended impacts of Outcome 1, Policy 1 and we believe would continue to do so if the pilot programme were to be repeated. With the currently available data, it is not possible to allocate specific GHG reductions to these actions, but it is feasible that without them the potential savings from the Agricultural Transformation Programme would not be made or sustained since these savings are based on improved expertise and frequency of use of the equipment. This includes, for example, Outcome 2, Policies 1-3, on increasing understanding of the importance and potential of climate action in the farming sector. These other policies and proposals (in particular Outcome 3, Policies 1-3) will have direct GHG savings beyond the livestock subsector but in this project, GHG savings can be allocated only to the livestock subsector because of the available baseline data provided by the SAC report.

It was not possible to quantify the impacts of the other policies as they did not have baselines or numerical targets.

[9] Sellars A, Beaton C, Bell J (undated). Estimate emissions reduction potential of items funded in the 2020/21 Sustainable Agriculture Capital Grants Scheme. Report by SAC Consulting, provided to this project by Scottish Government.

Table 4-2a. A summary of CCPu policies for the Agriculture sector – outcomes 1 and 2

Outcomes	Policies and proposals
Outcome 1: A more productive, sustainable Agriculture sector that significantly contributes towards delivering Scotland's climate change, and wider environmental, outcomes through an increased uptake of climate mitigation measures by farmers, crofters, land managers and other primary food producers	Policy 1: Scale up the Agricultural Transformation Programme across all the policies, including monitoring to assess the effectiveness of the pilot Sustainable Agricultural Capital Grant Scheme that will enable farmers and crofters to purchase equipment that should assist in reducing their greenhouse gas emissions, and support practice change
	Proposal 1: Develop rural support policy to enable, encourage and where appropriate, require the shift to low carbon, sustainable farming through emissions reduction, sustainable food production, improving biodiversity, planting biomass crops and appropriate land use change developed in line with just transition principles.
Outcome 2: More farmers, crofters, land managers and other primary food producers are aware of the benefits and practicalities of cost-effective climate mitigation measures.	Policy 1: The dissemination of information and advice on climate change mitigation measures in agriculture through a range of communication methods utilising technology and all media to best effect.
	Policy 2: An agri-tech group will be established to share, disseminate and encourage adoption of advances in agricultural science and technology as widely as possible.
	Policy 3: Launch a new and expanded peer to peer knowledge transfer initiative based on the success of our Young Climate Change Champions work.
	Proposal 1: Carbon Audits: in 2018, we will consult on how best to ensure maximum take up of carbon audits and how to enable tenant farmers and crofters in particular to benefit.
	Proposal 2: We will explore with stakeholders, including the Scottish Tenant Farmers Association and the Tenant Farming Commissioner, how best to engage tenant farmers to increase understanding of the environmental and economic benefits of low carbon farming.

Table 4-3b. A summary of CCPu policies for the Agriculture sector – outcomes 3

Outcomes	Policies and proposals
Outcome 3: Nitrogen emissions, including from nitrogen fertiliser, will have fallen through a combination of improved understanding, efficiencies and improved soil condition	Policy 1: Communicate and demonstrate the benefits of precision farming and nitrogen use efficiency in order to achieve a reduction in GHG emissions.
	Policy 2: Work with the agriculture and science sectors regarding the feasibility and development of a SMART (specific, measurable, achievable, relevant and time bound) target for reducing Scotland's emissions from nitrogen fertiliser.
	Policy 3: From 2018 we expect farmers to test the soil on all improved land every five or six years, and we will work with them to establish how best to achieve this.

Most policies and proposals did not have tangible targets or actions that will lead to quantifiable GHG impacts. For example, some were about provision of information or advice, and others involved investigating how mitigation actions could be implemented. Thus an analysis of the policy development assumptions was undertaken. The CCPu for agriculture was reviewed to identify all the GHG mitigation measures referred to directly or indirectly inferred to in our judgement of how policy aspirations could be implemented.

We estimated the GHG mitigation potential for each of the measures identified. This was informed by Lampkin et al. (2019), Eory et al. (2021), together with our own previous work (including our work to review agricultural GHG mitigation actions for the European Commission). This was backed up by a rapid evidence assessment (REA) to fill any knowledge gaps.

Using these various information sources, we estimated a mitigation potential per ha or livestock head using relevant area/headage factors. We scaled up the estimates to Scottish national level using the Scottish agricultural census data (Scottish Government; 2020a) to identify the maximum potential for individual measures that could be quantified. Average values over the period 2015 to 2020 were used.

We then estimated annual additional uptake potential for each mitigation action. Data on current uptake of mitigation actions in the UK and in Scotland are incomplete. Some data are available from government surveys by Defra and the Scottish Government but estimates of the likely uptake above the existing levels of uptake required expert judgement. In doing this we have drawn upon our experience of providing estimates of mitigation action uptake for the European Commission and used literature evidence where available.

The combined effects of mitigation actions at a Scottish level are not the same as the sum of the mitigation potentials for each action. This is because not all mitigation actions are independent of each other: for example, adoption of one mitigation action can affect the uptake of another mitigation action. Therefore, we assessed all mitigation actions for interactions and those that are not independent were placed into groups. We then estimated the mitigation potential for the group, and sub-sets of the group.

4.2.2 Phase 2 – Outcomes

The additional modelling undertaken during Phase 2 consisted of updates to the modelling assumptions, rather than a change in the overall level of ambition. Key changes to the modelling, as identified during the Phase 2 sector workshop, are summarised below.

The Scottish Government requested the team to reflect in the modelling improved uptake estimates for better nitrogen use and manure practices to reflect changes in the General Binding Rules on Silage and Slurry[10], a further round of the Capital Grant Scheme, and some allowance for methane breeding potential post 2030. These three elements had developed since the original CCP update was published. Furthermore, the Scottish Government, in their Vision for Agriculture, state that they will integrate enhanced conditionality (on climate and nature) of at least half of all funding for farming and crofting by 2025. The conditions are not yet defined, but there is expected to be a focus on management measures, with benefits for reduced climate impact. Another element is preparing for sustainable farming, with measures such as support and uptake for soils testing and carbon audits, but it is not clear, quantitatively, what these will deliver.

Other changes expected to impact GHG emissions projections include the following.

- ‘My Herd Stats’ will provide more accessible data to livestock farmers- starting with dairy and beef.
- Amendments to the Water Environment (Controlled Activities) (Scotland) Regulations 2011, on storage and use of slurry and digestate, are being implemented in a phased approach, starting from 1 January 2022, with particular rules on using LESS (low emission slurry spreading) equipment from 1 January 2023.
- There will be a further round of the capital grant scheme focusing on storage covers and precision farming equipment.
- There is a Scottish Government Programme for Government (PfG) commitment to double the organic production area.
- Peer-to-peer learning and other knowledge transfer are being encouraged, albeit with a recognition that the outcomes are uncertain; this includes the Small Woodland Loan Scheme, the Agriculture, Biodiversity and Climate Change Network, and the Integrating Trees Network scheme.

Only one take-up scenario was considered, consisting of improved uptake estimates for better nitrogen use and manure practices so as to reflect changes in the General Binding Rules on Silage and Slurry, a further round of the Capital Grant Scheme, and some allowance for methane breeding potential post 2030, as noted above.

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[10] Amendments on storage and use of slurry and digestate made to the Water Environment (Controlled Activities) (Scotland) Regulations 2011

4.2.3 Summary of Policy Packages

The table below indicates which policies were found to have the biggest potential impact within each package, which policies overlap with (or reinforce) each other, and which policies act as supporting measures.[11]

As explained previously, the emissions reductions that have been quantified for the agriculture sector are primarily due to Outcome 1, Policy 1 which is to scale up the Agricultural Transformation Programme. The other policies in the CCPu are considered supporting measures and could not be quantified separately. The table below presents the full suite of policies included in package A1.

In addition to the CCPu policies, which were grouped into Package A1, this study also drew on evidence from a separate report, produced by Ricardo on behalf of the World Wide Fund for Nature (WWF). It is important to note that the WWF study was part of a separate piece of work and that it is not a CCPu policy; however, in agreement with Scottish Government, it has been used as evidence to support this analysis. For more information refer to Section 4.3.4.

[11] The following descriptions have been used:

- **Key policies** are those that are expected to have the largest direct, tangible impacts on emissions, relative to others within each package.
- **Supporting measures** are those that will not have a direct, quantifiable impact on emissions, but may create an enabling environment or facilitate development of further policies/actions that will have a direct impact.
- **Overlapping/reinforcing measures** are those that interact with (and often contribute to the same activity impacts as) other policies - modelling these policies separately without consideration of interactions with other policies would incur double counting of emissions reductions.

Table 4-4a. Policy packages for the Agriculture sector - A1 Agricultural transformation

Policy	Categorisation
Policy 1: Scale up the Agricultural Transformation Programme across all the policies, including monitoring to assess the effectiveness of the pilot Sustainable Agricultural Capital Grant Scheme that will enable farmers and crofters to purchase equipment that should assist in reducing their greenhouse gas emissions, and support practice change	Key policy
Proposal 1: Develop rural support policy to enable, encourage and where appropriate, require the shift to low carbon, sustainable farming through emissions reduction, sustainable food production, improving biodiversity, planting biomass crops and appropriate land use change developed in line with just transition principles.	Supporting measure
Policy 1: The dissemination of information and advice on climate change mitigation measures in agriculture through a range of communication methods utilising technology and all media to best effect.	Supporting measure
Policy 2: An agri-tech group will be established to share, disseminate and encourage adoption of advances in agricultural science and technology as widely as possible.	Supporting measure
Policy 3: Launch a new and expanded peer to peer knowledge transfer initiative based on the success of our Young Climate Change Champions work.	Supporting measure
Proposal 1: Carbon Audits: in 2018, we will consult on how best to ensure maximum take up of carbon audits and how to enable tenant farmers and crofters in particular to benefit.	Supporting measure
Proposal 2: We will explore with stakeholders, including the Scottish Tenant Farmers Association and the Tenant Farming Commissioner, how best to engage tenant farmers to increase understanding of the environmental and economic benefits of low carbon farming.	Supporting measure
Policy 1: Communicate and demonstrate the benefits of precision farming and nitrogen use efficiency in order to achieve a reduction in GHG emissions.	Supporting measure
Policy 2: Work with the agriculture and science sectors regarding the feasibility and development of a SMART (specific, measurable, achievable, relevant and time bound) target for reducing Scotland's emissions from nitrogen fertiliser.	Supporting measure
Policy 3: From 2018 we expect farmers to test the soil on all improved land every five or six years, and we will work with them to establish how best to achieve this.	Supporting measure

Table 4-5b . Policy packages for the Agriculture sector - External stakeholder report (WWF)

Policy	Categorisation
Additional potential actions as per an earlier report produced for the WWF	N/A

4.2.4 Variation across scenarios

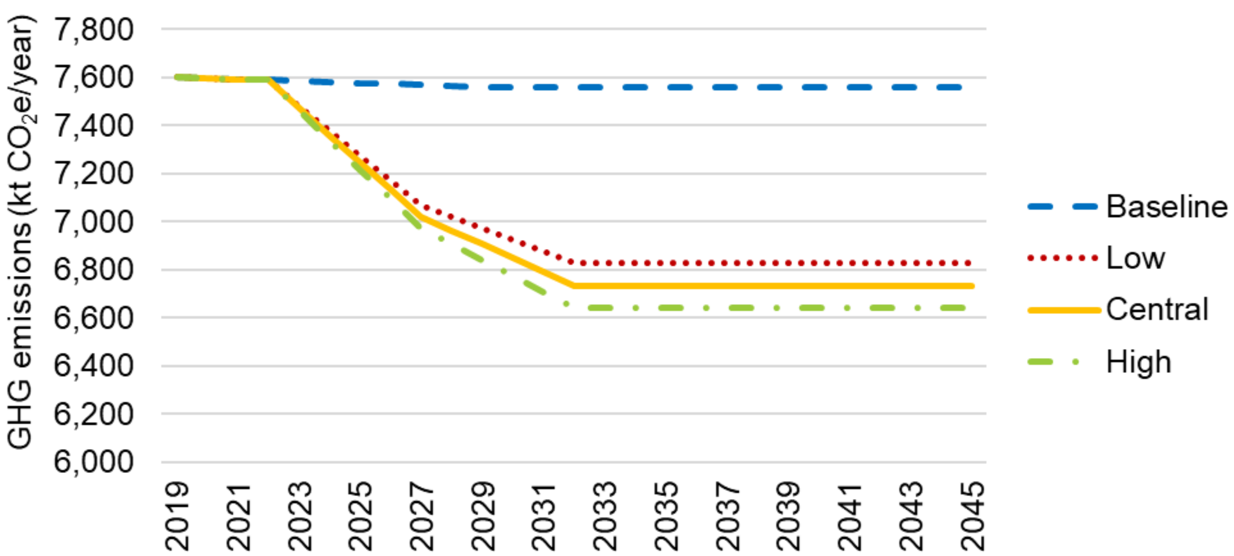
Due to the inelastic nature of the core food and drink products from Scotland coupled with high export reliance, the scenarios explored under this work are deemed not applicable to the Agriculture sector. However, some minor variation in projected emissions can be seen between scenarios under Phase 1 – this is to do with assumed variation in uptake of the main quantified policy for the Agriculture sector (Agricultural Transformation Fund) according to economic growth scenario, as this is a funding driven policy.

4.3 Emissions Projections

4.3.1 Phase 1 results

Total CO_2 emissions from the Agriculture sector shown in Figure 4-1 are expected to decline from nearly 7.6 Mt CO_2 in 2019 to between 6.6 and 6.8 Mt CO_2 by 2032 based on estimated outcomes of the policies in Table 4-2. The remaining emissions sources will be, like today, mainly methane from livestock (enteric fermentation) and their manures, and nitrous oxide from soil.

Figure 4-1. Phase 1 emissions projections under different scenarios for the Scottish Agriculture sector.

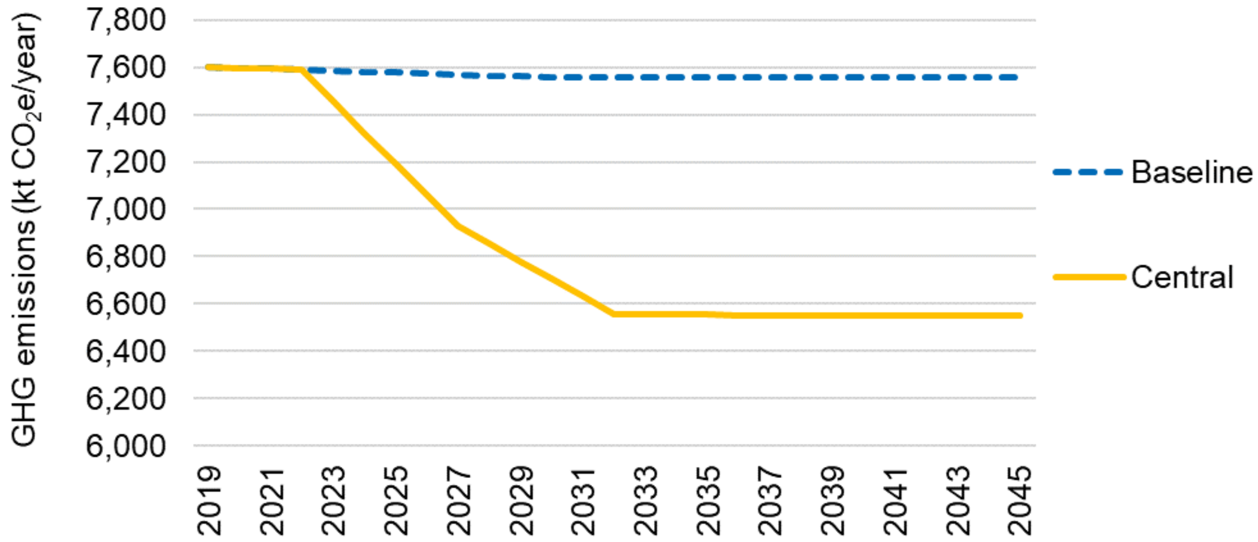


4.3.2 Phase 2 results

The additional modelling work resulted in changes in the modelling outputs, as shown in Figure 4-2; this modelling was based on only one take-up scenario. The expected increase in activity on improving nutrient and manure use efficiency reflecting the stepped introduction of the new General Binding Rules for example, produces a reduction in GHG emissions, as shown in

Figure 4-3, and Table 4-6 quantifies these results. You will notice there is a levelling-off of results after 2030 as improved behaviours of nitrogen and manure management can only go so far before impacting production.

Figure 4-2: Phase 2 emissions projections under one take-up scenario for the Agriculture sector



It is worth noting that due to the interrelated nature of farming systems, different policy packages will have impacts on each other and are therefore difficult to identify a particular allocation of savings. For example, an improved advice and knowledge system will support the implementation of best practice, as will availability of funding for better technical equipment. However, neither of these policies can guarantee best practice. The transitional changes to the General Binding Rules are expected to have the most impact.

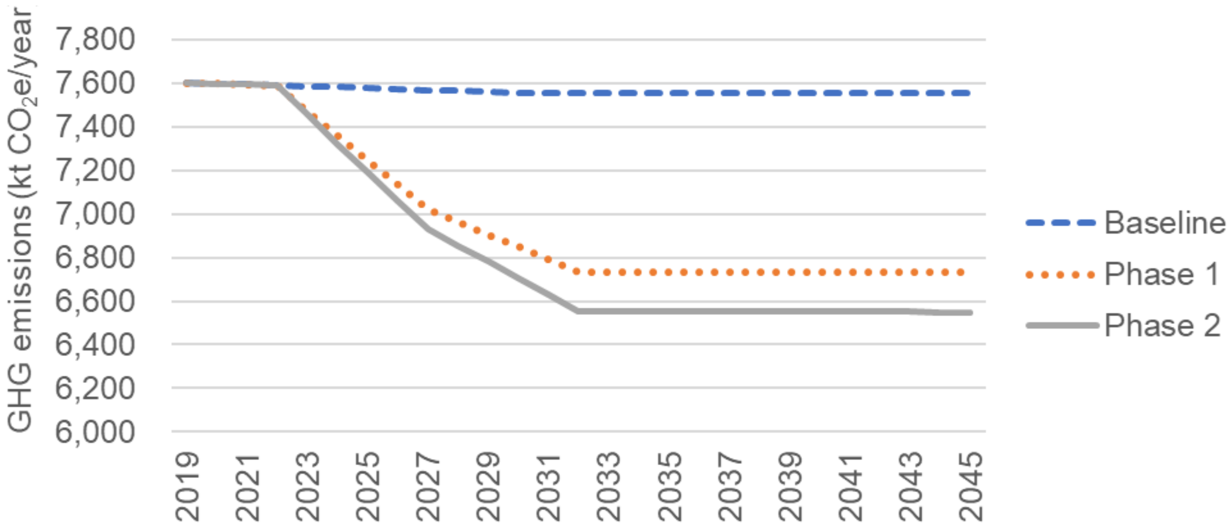
4.3.3 Comparison of Phases 1 & 2

Figure 4-3 shows the difference in estimates of emissions between Phases 1 (central scenario) and 2 of the project and the 2019 baseline. As stated previously, the difference between Phases 1 and 2 is due to changes in the modelling assumptions rather than changes in the overall level of ambition that was assumed. Table 4-6 provides more detail on the individual take-up scenarios and their estimated changes over time compared to the single take-up scenario estimated in Phase 2.

Table 4-6: Emission projections for the Agriculture sector under the baseline and under modelled scenarios, for both Phase 1 and Phase 2 (in $ktCO_2e$)

Phase	Scenario	Emissions ($ktCO_2e$)						
		2019	2020	2025	2030	2035	2040	2045
	Baseline	**7,601**	**7,597**	**7,577**	**7,557**	**7,557**	**7,557**	**7,557**
1	**Central Growth**	**7,601**	**7,597**	**7,243**	**6,850**	**6,734**	**6,734**	**6,734**
	High Growth	7,601	7,597	7,214	6,774	6,639	6,639	6,639
	Low Growth	7,601	7,597	7,271	6,925	6,828	6,828	6,828
2	**Central Growth**	**7,601**	**7,597**	**7,188**	**6,707**	**6,554**	**6,551**	**6,550**
	High Growth	7,601	7,597	7,188	6,707	6,554	6,551	6,550
	Low Growth	7,601	7,597	7,188	6,707	6,554	6,551	6,550

Figure 4-3: Differences in emissions from the Agriculture sector between the modelling results from the Baseline scenario, and the Central scenarios in Phases 1 and 2



4.3.4 Emissions reduction by policy package (2032) – Phase 1 & 2

This section presents results on the emission reductions of each policy outcome considered in the model. The table below provides a further breakdown of the estimated emissions from policy package A1 which focused on the Capital Grant Scheme, and new policies such as the changes to the binding rules for water.

Table 4-7. Emission reduction contributions (in $ktCO_2e$) of Agriculture sector policy packages under model scenarios by 2032, with respect to the baseline

Policy Package	Emissions reductions by 2032 ($ktCO_2e$)					
	Phase 1			Phase 2		
	Central Growth	High Growth	Low Growth	Central Growth	High Growth	Low Growth
A1	-244	-244	-244	-244	-244	-244
Total	**-244**	**-244**	**-244**	**-244**	**-244**	**-244**

Further emissions reductions have been included from potential mitigations as part of CCPu agricultural policies as estimated from the WWF “Reaching Net Zero in Scotland” report[12]. The WWF study (Wiltshire et al., 2021) assessed the potential for GHG emissions mitigation in agriculture, by 2032, that could arise from implementation of recommendations in other reports, including the Scottish Government’s Climate Change Plan Update (CCPu). Recognising that the CCPu proposed policies and actions that are mainly to explore further policies to drive uptake of mitigation actions, an interpretation was made of how CCPu policies and actions could lead to on-farm mitigation actions by 2032. The WWF report concluded that the mitigation potential, based on an interpretation of the CCPu, was not sufficient to reach the CCPu GHG mitigation target (for 2032) of 5.3 Mt $CO_2e\ y^{-1}$. Further conclusions included:

- The extent of GHG emissions mitigation will be dependent on both the quality of mitigation action implementation and the extent to which additional mitigation action uptake is achieved.
- A further challenge in the pursuit of the CCPu target is the availability of data; better and more activity data (e.g., from farm surveys) will be needed to monitor progress, including uptake of mitigation actions.

4.4 Uncertainties

In our judgement, uncertainties in the historical estimates of emissions are high relative to other sectors, and uncertainties in projections of GHGs are even higher.

4.5 Sensitivities

The projected GHG emissions for agriculture in Scotland are sensitive to ruminant livestock population (mainly sheep and cattle) because ruminant livestock population is the main driver of enteric fermentation and the associated emission of methane. Enteric fermentation emissions dominate agriculture GHG emissions in Scotland.

Emissions of nitrous oxide from soil are also a major component of the GHG emissions total for agriculture in Scotland, and projections of these emissions are sensitive to

[12] Wiltshire et al., *‘Reaching Net Zero in Scotland Emissions reductions in agriculture’* (2021). Available from: https://www.wwf.org.uk/sites/default/files/2021-10/Ricardo%20GHG%20mitigation%20WWF%20Scotland%2017Oct21.pdf

nitrogen inputs to land, including inorganic (manufactured) nitrogen fertiliser and organic nitrogen inputs such as livestock manures.

5. Buildings sector

5.1 Sector Overview

5.1.1 Sector Background

Although emissions from the Buildings sector by source are relatively modest, end use emissions – which consider the GHG emissions from electricity use and the direct consumption of fuel – are much larger. Emissions from buildings in the Services and Residential Climate Change Plan (CCP) reporting categories accounted for just over 20% (8.6 $MtCO_2e$) of Scotland's emissions in 2020.[13] In terms of targeting GHG emission reductions, the Building sector is therefore important.

The Climate Change Plan Update (CCPu)[14] states that there will be a major shift in the type of energy consumed from fossil fuels to electrical energy: "The zero emissions heat transition will involve […] moving from high emissions heating systems, reliant on fossil fuels, to low and zero emissions systems such as heat pumps, heat networks and potentially hydrogen."

5.1.2 Subsectors Considered

The Buildings sector was disaggregated into the following subsectors:

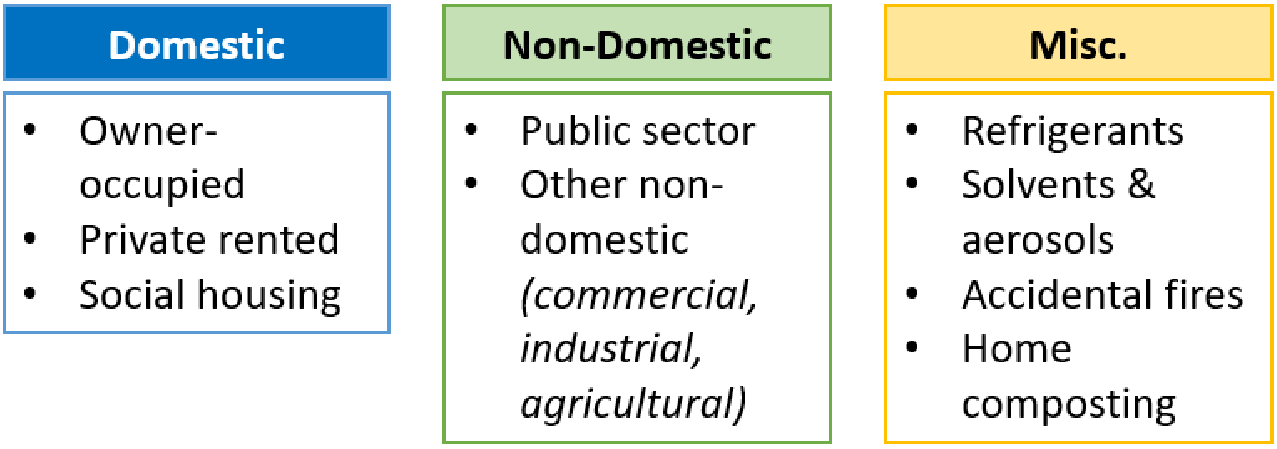
- Domestic – owner occupied
- Domestic – private rented
- Domestic – social rented
- Non-domestic – public
- Non-domestic – other (includes commercial buildings, as well as buildings associated with Agriculture and Industry
- Miscellaneous – includes refrigerants, solvents & aerosols, accidental fires, and home composting, which are allocated to the buildings sector in the inventory

The structure of the Buildings sector, as modelled in this study, is shown below. Note that no measures were modelled for the 'Miscellaneous' category.

[13] Scottish Government, '*Scottish Greenhouse Gas Statistics 2020'* (published 2022). Available at: https://www.gov.scot/publications/scottish-greenhouse-gas-statistics-2020/

[14] Scottish Government, '*Update to the Climate Change Plan 2018 – 2032: Securing a Green Recovery on a Path to Net Zero'* (16 Dec 2020). Available at: https://www.gov.scot/publications/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/

Figure 5-1. A visualisation of the disaggregation of the Buildings sector



5.1.3 Data Sources

The main data sources used to undertake the assessment of the Buildings sector are detailed in Table 5-1 below.

Table 5-1. A summary of the different data sources used in the assessment of the Buildings sector.

Purpose	Data used	Comment
GHG inventory for Scotland	**UK National Atmospheric Emissions Inventory (UK NAEI)**	GHG inventory for Scotland needed to estimate impacts of policies on emissions.
Energy consumption in Scotland	**BEIS Sub-National Total Final Energy Consumption**	Energy consumption in Scotland needed to estimate impacts of policies on energy use.
Disaggregating non-domestic fuel consumption and electricity data	**Digest of UK Energy Statistics (DUKES)**	Split (%) of non-domestic energy use (i.e., between commercial, public, agricultural buildings, and industrial buildings) used to inform disaggregation of non-domestic energy use by sub-sector.
Disaggregating domestic fuel consumption and electricity data	**Scottish Housing Survey (SHS)**	Tenure split (%) of domestic buildings in Scotland used to disaggregate domestic energy use by sub-sector.
Split of fuel consumption by end use	**Energy Consumption in the UK (ECUK) End Use Tables**	Fuel consumption by sector and end use (%) was used to ensure that measures impacting heat demand were scaled based on the proportion of energy used for that purpose in each sub-sector.

A wide variety of other datasets have been referred to in order to assess the impacts of individual policies. These additional references are provided for each policy below in Appendix 3.

5.1.4 Underlying Drivers of Energy & Emissions

There are many drivers of energy use in this sector, including but not limited to: energy efficiency, energy prices, weather, the number and type of buildings, consumer behaviour, household incomes, and standards of repair/maintenance.

Within buildings and other stationary facilities, energy may be used for a variety of purposes. In domestic buildings, energy uses tend to be dominated by space and water heating, lighting, cooking, and electronic appliances. In non-domestic buildings, these may represent a smaller portion of overall energy use, due to the additional presence of (for example) ventilation and air conditioning systems, lifts, escalators, IT, refrigeration, and other equipment or machinery.

For the purpose of this assessment, given the constraints on scope and budget, we have assumed that the main driver of emissions in the domestic sector is the number of dwellings. In the absence of data on the anticipated number and timing of new housing delivery, we have used National Records of Scotland (NRS) projections of household numbers as a rough proxy.[15]

In the non-domestic sector, the number of buildings is assumed to be less of a key driver than the scale and type of economic activities that are being carried out within those buildings. Therefore, as a simplifying assumption, for the purpose of this assessment we have scaled growth in the non-domestic sector with projected changes in GVA.

5.2 Policy Measures and Outcomes Modelled

5.2.1 Phase 1 – Policy Measures

For the Buildings sector, there were 48 policies to be assessed. However, there was a lack of available data to quantify many of these policies. Instead, policies were split into packages covering similar themes, to allow policies targeting the same measures to be assessed together and thus ensure interactions between similar policies/proposals were captured. For example, there are multiple policies addressing energy efficiency in existing buildings, which will have a combined effect on the energy demands of the building stock.

The table below shows the packaging of policies into key themes, and the quantifiable targets informing the assessment. Note that, at the request of the Scottish Government, some of the targets were taken from the Heat in Buildings Strategy but may not be in the CCPu.[16]

[15] NRS, *'Household Projections for Scotland, 2018-based'* (2020). Available at: https://www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/households/household-projections/2018-based-household-projections

[16] Scottish Government, *'Heat in Buildings Strategy – achieving net zero emissions in Scotland's buildings'* (2021). Available at: https://www.gov.scot/publications/heat-buildings-strategy-achieving-net-zero-emissions-scotlands-buildings/

Table 5-2a. A summary of CCPu policies for the Buildings sector- Existing buildings 1

Theme	Quantifiable targets	Relevant policies / strategies / actions
Existing buildings		

Upgrade fabric efficiency	**From the Heat in Buildings Strategy:**
	• Minimum Energy Performance Certificate (EPC) equivalent ratings to be achieved for domestic buildings:
	  o Private rented – C equivalent by 2028
	  o Owner-occupied – C equivalent by 2033
	  o Social – B by end-2032 (note link to EESSH)
	• Note: Scottish Government will be consulting on the regulatory approach for non-domestic buildings so there are no quantitative targets, although these would be impacted by the SME advice/loans, HIBS Social Housing Decarbonisation funding, and any other sector-wide initiatives or legislation.
		• Energy Company Obligation (ECO)
		• HiBS domestic and SME Delivery Schemes
		• Energy Efficiency Standard for Social Housing (EESSH)
		• Private Rented Sector Minimum Energy Efficiency Standards
		• HIBS Social Housing Decarbonisation funding
		• Heat in Buildings regulation

Table 5-3b. A summary of CCPu policies for the Buildings sector – Existing Buildings 2

Theme	Quantifiable targets	Relevant policies / strategies / actions
Existing buildings		

Replacement of heating systems	• Phase out new or replacement fossil fuel boilers [proposed but not yet confirmed]:
	  ○ Off-gas grid properties from 2025
	  ○ On-gas grid properties from 2030
	• All buildings to have zero direct emission heating systems (ZDEH) by 2045 at the latest
	• “Decarbonise the equivalent of 50,000 non-domestic buildings”
	Heat in Buildings Strategy includes a provisional target for at least 22% of non-electrical heat in buildings to be directly supplied by renewable sources by 2030 (not modelled to avoid double-counting with the other targets relating to heating system replacement)
		• ECO
		• HiBS domestic and SME Delivery Schemes
		• Energy Efficiency Standard for Social Housing (EESSH)
		• Private Rented Sector Minimum Energy Efficiency Standards
		• HIBS Social Housing Decarbonisation funding
		• Heat in Buildings regulation
		• Renewable Heat Incentive (RHI) (closed)
		• Local Heat and Energy Efficiency Strategies (LHEES)

Installation of smart meters	• All homes and businesses to be offered a smart meter by 2020 under a UK Government initiative • All gas and electricity suppliers have binding annual installation targets to roll out smart and advanced meters to their remaining non-smart customers by end of 2025	• Smart Meter Installation scheme

Table 5-4c. A summary of CCPu policies for the Buildings sector – New Buildings and Miscelleaneous

Theme	Quantifiable targets	Relevant policies / strategies / actions
New buildings		
Energy efficiency	N/a – technical standards have not yet been set at time of analysis	• Review of energy standards within Building Regulations • 'Develop and introduce future regulation for non-domestic buildings'
Low carbon heating systems	All new buildings to have zero carbon heating systems from 2024	• New Build Heat Standard (NBHS) • 'Develop and introduce future regulation for non-domestic buildings'
Miscellaneous		
Renewable electricity generation	No quantifiable targets for renewable electricity generation in buildings[17]; however, the Scottish Government aims to achieve 2GW of community and locally owned energy by 2030	• Community and Renewable Energy Scheme (CARES) (2021-2025) • Review of Permitted Development Rights (PDRs)
District Heat Networks (DHNs)	From the Heat in Buildings Strategy: "As part of the Heat Networks (Scotland) Act we have new targets for the amount of heat to be supplied by heat networks. These require the combined supply of thermal energy by heat networks to reach 2.6 TWh of output by 2027 and 6 TWh of output by 2030. This is 3% and 8% respectively of current heat supply."	• District Heating Loan Fund (DHLF) • Heat Networks Development Plan (HNDP) • Heat Networks (Scotland) Act
Hydrogen	"Progress to 20% of Scottish gas demand accounted for by biomethane and hydrogen blended into the gas network by 2030."	• UK Green Gas Support Scheme (GGSS)

[17] The Scottish Government previously "set a target for 11% of non-electrical heat demand in Scotland to be met from renewable sources, such as biomass or heat pumps, by 2020." According to the EST, as of 2020 around 6.4% of non-electrical heat demand was met from renewable sources. Further progress against this specific target was not modelled since it was not included in the CCPu or HiBS. For more information, see EST, *'Renewable Heat in Scotland'* (2021). Available at: https://energysavingtrust.org.uk/report/renewable-heat-in-scotland-2020/

Details of the modelling approach taken for each policy are provided in Appendix 3.

In agreement with Scottish Government, the above list was reviewed to identify quantifiable policies and targets. In Phase 1, these were:

- Energy Company Obligation 2020-2026
- Smart meter installation
- New Build Heat Standard
- Heat in Buildings Regulation
- Upgrade homes to EPC 'C' [owner occupied and private rented only] or EPC 'B' [social housing only]
- Scottish Green Public Sector Estate Scheme
- Renewable Heat Incentive 2020-2022
- Decarbonise equivalent of 50,000 non-domestic buildings
- HiBS domestic and SME Delivery Schemes

5.2.2 Phase 2 – Outcomes

A workshop was held between representatives of the Scottish Government and Ricardo Energy & Environment to discuss options for modelling additional targets as part of Phase 2 of the Provision of Emissions Projections project. The workshop highlighted a few instances where a policy that was modelled in Phase 1 have been reframed; for example, the policy goal of decarbonising the equivalent of 50,000 non-domestic buildings by 2030 has been reframed as part of the policy goal of reducing service sector fossil fuel heat consumption to 5,000 GWh per year by 2030. However, because the focus in Phase 2 is on overall targets rather than individual policies, this has no impact on the results.

As part of Phase 2, it was agreed that the modelling would assume 400,000 on-gas homes are converted to ZDEH technologies by 2030, with the remaining stock of on-gas homes being converted to ZDEH between 2030 and 2045. The Scottish Government are developing proposals for regulations which would be designed to deliver a pathway towards their target of over 1 million on-gas homes converting to ZDEH by 2030, and aim to consult on these proposals as part of a Heat in Buildings Bill in 2023. The smaller number of 400,000 assumed in this assessment is intended to illustrate the effect that any delay or amendments made as a result of the consultation and Parliamentary processes may have on the pace and extent of compliance that the proposed regulations may deliver.

The table below shows the additional targets that were considered during Phase 2. These are predominately based on the targets listed in the Climate Change Plan Monitoring Report 2022, although they have been modified to reflect subsequent discussions between Ricardo and Scottish Government.

Table 5-5. Additional targets considered during Phase 2 in the Buildings sector

Outcome	Target(s)
1. The heat supply to our homes and non-domestic buildings is very substantially decarbonised, with high penetration rates of renewable and zero emissions heating	1. Zero Direct Emission Heating (ZDEH): a) Transition over 1 million domestic buildings to ZDEH by 2030. The Scottish Government aims to consult this year on proposed legislation designed to enable this. b) From 2024 onwards, all new domestic buildings will be fitted with ZDEH from the outset as per the proposed New Build Heat Standard. c) From 2030 onwards, all remaining buildings are assumed to begin transitioning to ZDEH in line with the proposed Heat in Buildings Regulation. (Note, for most buildings this process concludes in 2045 whereas for the public sector this process concludes in 2038.)
	2. Reduce service sector fossil fuel heat demand to 5,000 GWh by 2030.
2. Our homes and buildings are highly energy efficient, with all buildings upgraded where it is appropriate to do so, and new buildings achieving ultra-high levels of fabric efficiency	3. Reduce energy intensity of residential buildings (MWh per household) by at least 30% by 2032 (on 2015 levels).
	4. All homes have EPC C or equivalent (or higher) by 2033, where technically feasible and cost-effective including backstop dates.
	5. Reduce emissions intensity of non-domestic buildings (tCO_2e per GVA) by 20% by 2025 and 30% by 2032 compared with 2015.
3. Our gas network supplies an increasing proportion of green gas (hydrogen and biomethane) and is made ready for a fully decarbonised gas future	6. Progress to 20% of Scottish gas demand accounted for by biomethane and hydrogen blended into the gas network by 2030.
4. The heat transition is fair, leaving no-one behind and stimulates employment opportunities as part of the green recovery	7. Not quantifiable

There are interactions between some of these targets:

- In the domestic sector:
    - Improving EPC ratings will reduce the impact of switching to ZDEH. This is because, once the buildings are upgraded to be more energy efficient, emissions from heating are assumed to be reduced, so when these heating systems are replaced with zero emission alternatives, the emissions savings will be lower. Despite this, improving energy efficiency is necessary in order to improve the performance of ZDEH systems and reduce electricity demand.
    - Improving EPC ratings and switching to ZDEH will both contribute towards reducing the energy intensity of domestic buildings. Conversely, reducing the energy intensity of domestic buildings would likely involve improving EPC ratings and switching to ZDEH. Therefore, modelling the energy intensity target simultaneously with the EPC and ZDEH targets would result in double-counting.
- In the non-domestic sector:
    - Reducing fossil fuel consumption to 5,000 GWh per year is expected to reduce the emissions intensity. Conversely (similar to the domestic sector, see previous bullet point) reducing emissions intensity will likely involve reducing fossil fuel consumption.
- Blending "green gas" into the gas grid would impact the calculated emissions savings from all of the other targets for both the domestic and non-domestic sectors. For example, if the gas grid is blended with hydrogen, emissions from gas would be lower, which means that the impact of increasing energy efficiency and switching to ZDEH would be lessened.

Because some of these targets contribute towards one another, it was not possible to model all of them separately. In particular, our calculations suggest that Target 3 (reduce domestic energy intensity) and Target 5 (reduce non-domestic emissions intensity) would be met or exceeded if the other targets were achieved.

The table below compares the policies that were quantified in Phase 1 versus Phase 2.

Table 5-6. Buildings sector policies modelled in Phases 1 and 2

Description	Phase 1	Phase 2
Energy Company Obligation 2020-2026	✓	
Smart meter installation	✓	
New Build Heat Standard	✓	✓
Heat in Buildings Regulation*	✓	✓
Upgrade remaining homes to EPC 'C' [owner occupied and private rented only]	✓	✓
Upgrade remaining homes to EPC 'B' [social housing only]	✓	✓
Scottish Green Public Sector Estate Scheme	✓	
Renewable Heat Incentive 2020-2022	✓	
Decarbonise equivalent of 50,000 non-domestic buildings**	✓	
Reduce service sector fossil fuel demand to 5,000 GWh per year		✓
HiBS domestic and SME Delivery Schemes ***	✓	
Blend biomethane and hydrogen into the gas network		✓

* In Phase 1, this was implemented starting in 2030. In Phase 2, all off-gas homes heated by fossil fuels are converted to ZDEH between 2025 and 2030. A further 400,000 on-gas homes are converted to ZDEH by 2030. The remaining on-gas homes are then converted linearly between 2030 and 2045.

** This target was reframed after Phase 1 to be included as part of the target of reducing service sector fossil fuel demand to 5,000 GWh p.a.

*** Including the ABS, WHS and HES plus the additional capital funding announced as part of the Bute House Agreement

To summarise the differences between these: In Phase 1, we modelled the impacts of EPC upgrades to domestic buildings, and the proposed Heat in Buildings Regulation which would see all buildings switch to zero direct emission heating (ZDEH), alongside specific initiatives such as the Energy Company Obligation, smart meter installations, HiBS domestic and SME Delivery Schemes and the Scottish Green Public Sector Estate Scheme. In Phase 2, we modelled EPC upgrades to domestic buildings, reducing service sector fossil fuel demand to 5,000 GWh per year, and the entire building stock transitioning to ZDEH. Initiatives such as the HiBS domestic and SME Delivery Schemes were assumed to contribute to those outcomes so were not modelled separately. Also in Phase 2, the 'High Hydrogen' scenario explored the impact of blending up to 20% green hydrogen into the gas network by as an interim measure prior to the wider adoption of electrically powered ZDEH.

Other points to note:

- Whereas in Phase 1, some policies were modelled differently depending on high/low economic growth, reflecting (for example) greater uptake of some mitigation measures in the event that more funding was available, in Phase 2, growth is assumed to be the same across each scenario, so there is no difference between them. The exception is the ‘High Hydrogen’ scenario, where the key difference is that green hydrogen is assumed to be blended into the gas grid at 20% by volume by 2030.

- As in Phase 1, the target of improving EPC ratings was taken as a proxy for improving energy efficiency, even though at present this can be achieved through changing heating systems or installing renewable technologies as well.

5.2.3 Summary of Policy Packages

The table below indicates which policies were found to have the biggest potential impact within each package, which policies overlap with (or reinforce) each other, and which policies act as supporting measures.[18]

Note that energy efficiency measures in existing buildings were split between those that are funded as part of Scottish Government schemes (such as the Area-Based Schemes, Warmer Homes Scotland and Home Energy Scotland), and those that would rely on other sources of funding to be delivered (such as the minimum EPC standards for private rented properties).

Table 5-7a. Policy packages for the Buildings sector – B1 Energy Efficiency Measures (SG Funded)

Policy Package	Policy	Categorisation
B1 Energy efficiency measures (SG funded)	Policy 2: HiBS domestic and SME Delivery Schemes: - Area Based Schemes and Warmer Homes Scotland; - Home Energy Scotland Advice Service and Loans; - Home Energy Scotland cashback scheme for zero emissions heating technologies and energy efficiency measures; - SME Advice Service and Loans; - SME cashback scheme for zero emissions heating technologies and energy efficiency measures.	Key policy
	Policy 11a: Expanded £1.8bn HIBS Social Housing Decarbonisation funding over the next parliament. That includes • At least £465m to support those least able to pay • £200m Social Housing Net Zero Heat Fund,	Key policy

[18] The following descriptions have been used:

- **Key policies** are those that are expected to have the largest direct, tangible impacts on emissions, relative to others within each package.
- **Supporting measures** are those that will not have a direct, quantifiable impact on emissions, but may create an enabling environment or facilitate development of further policies/actions that will have a direct impact.
- **Overlapping/reinforcing measures** are those that interact with (and often contribute to the same activity impacts as) other policies - modelling these policies separately without consideration of interactions with other policies would incur double counting of emissions reductions.

Table 5-8b. Policy packages for the Buildings sector – Package B2 and other policies

Policy Package	Policy	Categorisation
B2 Energy efficiency measures (not SG funded)	Policy 9: Re-introduce revised regulations to the Scottish Parliament requiring mandatory minimum energy efficiency standards for the Private Rented Sector, to come into force from 2022.	Key policy
	Policy 5: Energy Efficiency Standard for Social Housing: will be met by social landlords by 2020.	Key policy
	Policy 24: Work with social landlords to bring forward the review of the existing Energy Efficiency Standard for Social Housing (EESSH2) with a view to strengthening and realigning the standard with net-zero requirements.	Supporting measure
Individual policy Energy Company Obligation	Policy 1: Energy Company Obligation (ECO) requires obligated energy supply companies to deliver energy efficiency measures in homes – mainly insulation-based measures and boiler replacements.	Key policy
Individual policy New Build Zero Emissions from Heat Standard	Policy 6: 2024 New Build Zero Emissions from Heat Standard: requiring new buildings to have zero emissions heating systems.	Key policy
Individual policy Heat in Buildings Regulation	Policy 8: Heat in Buildings regulation: Put in place regulation to increase uptake of zero emissions heating systems and improve energy efficiency standards across all tenures, prioritising the raising of standards for households living in fuel poverty.	Key policy
Individual policy Scottish Green Public Sector Estate Scheme	Policy 11c: £200m Scottish Green Public Sector Estate Scheme	Key policy
Individual policy The Renewable Heat Incentive	Policy 13: The Renewable Heat Incentive (RHI) - a GB-wide scheme created by the UK Government (with the agreement of the Scottish Government). UK Government is extending both the domestic and non-domestic RHI out to 2022.	Key policy

Table 5-9c. Policy packages for the Buildings sector – other policies

Policy Package	Policy	Categorisation
Individual policy (Phase 1) Decarbonise non-domestic buildings	Policy 21: Assessment of Energy Performance and Emissions Regulations (Non-Domestic Buildings). The Assessment of Energy Performance of Non-domestic Buildings (Scotland) Regulations 2016 require assessment of the energy performance and emissions of larger non-domestic buildings (those over 1,000 m^2). Note that, through discussions with the Scottish Government, it was agreed to model this as 'Decarbonise the equivalent of 50,000 non-domestic buildings'	Key policy (Replaced in Phase 2 by the targets below)
BX2 (Phase 2) Decarbonise non-domestic buildings	Target: Reduce service sector fossil fuel heat demand to 5,000 GWh by 2030	Key target
	Target: Reduce emissions intensity of non-domestic buildings (tonnes of CO_2e per GVA) by 20% by 2025 and 30% by 2032 compared with 2015	Overlapping/reinforcing
BX1 (Phase 2) Blending biomethane and hydrogen into the gas network	Target: Progress to 20% of Scottish gas demand accounted for by biomethane and hydrogen blended into the gas network by 2030	Key target

5.2.4 Variation across scenarios

Some of the measures that were modelled vary across scenarios, while others do not.

Policies that are associated with a fixed amount of funding, such as the HiBS domestic and SME Delivery Schemes or the Scottish Green Public Sector Estate Scheme, are assumed not to vary across scenarios.

Policies that represent an either/or option are also assumed not to vary. An example would be the New Build Heat Standard, which would require new buildings to use ZDEH. We have assumed that this would be implemented regardless of the level of economic growth or hydrogen availability.

However, where there are measures that could be adopted voluntarily by households, businesses, and the public sector, we have assumed that these would vary across the economic growth scenarios because that would impact the amount of money available to spend on such measures. Examples include uptake of retrofitting measures (as part of the EPC upgrades), or adoption of heat pumps (driven by the Heat in Buildings Regulation). We have assumed that in a high growth scenario, more people would choose to adopt these measures, so the rate of uptake is faster than in the central scenario. The opposite is true in the low growth scenario.

In Phase 1 we made the simplifying assumption that hydrogen would not be used to heat buildings. The Scottish Government's Hydrogen Action Plan states: "We do not consider that hydrogen will play a central role in the overall decarbonisation of domestic heat."[19] Therefore, there is no difference between the high and low hydrogen scenarios in Phase 1. The impact of blending hydrogen into the gas grid was modelled as part of Phase 2 under the high hydrogen availability scenario.

5.3 Emissions Projections

5.3.1 Phase 1 results

In the Baseline scenario, emissions show a small increase to 2045 due to new development and economic growth. In all other scenarios, there is a slow reduction in emissions in the mid to early 2020s, followed by an accelerated reduction later in the decade, but the most significant impacts occur from 2030 onwards due to the Heat in Buildings Regulation (more on this below).

Emissions reductions are driven by policies and funding schemes targeting retrofits and the installation of zero direct emissions heating in existing homes (e.g., HiBS domestic and SME Delivery Schemes, Energy Efficiency Standard for Social Housing, Private Rented Sector Minimum Energy Efficiency Standards, Heat in Buildings Regulation). In the high growth scenario, retrofitting rates are assumed to be higher, whereas the opposite is true in the low growth scenario.

The impact of tighter energy performance standards and zero direct emissions heating for new dwellings is relatively small, since (a) there are not many of them in comparison with the existing stock, and (b) they are already likely to be more energy efficient. Policies

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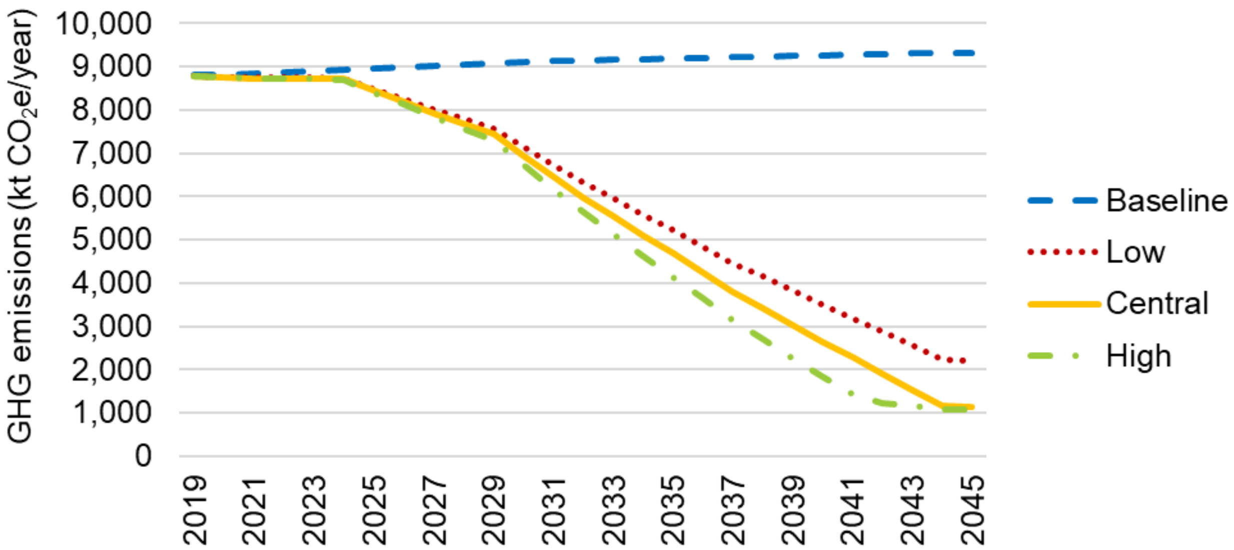
[19] Scottish Government, *'Hydrogen Action Plan'* (2022). Available at: https://www.gov.scot/publications/hydrogen-action-plan/

related to new buildings are best understood as mitigating the potential increase in emissions that would otherwise occur; understandably, they do not reduce existing sources of emissions.

By far the most impactful policy is the Heat in Buildings Regulation, which in this analysis is assumed to result in the near-total phaseout of fossil fuels in buildings. In the high growth scenario, we have assumed that this shift takes place more rapidly, whereas in the low growth scenario we have assumed that around 20% of buildings do not switch heating systems by 2045, resulting in a shortfall against the target. Note that the details of the Heat in Buildings Regulation have not yet been determined, so the actual impact of this policy is uncertain. At present, without details of the regulation, the emissions reductions presented here are considered to be highly optimistic, and effective implementation mechanisms will need to be identified to ensure that they are achieved.

In 2045 there would be some residual emissions from the building sector; these may include refrigerants and any wood or other fuels used as secondary heating.

Figure 5-2. Phase 1 emissions projections under all modelled scenarios for the Buildings sector as a whole



The main GHG reductions come from changes in fuel use, in particular the phase-out of fossil fuels in favour of decarbonised electricity. This is highlighted on the graphs below. In the Baseline scenario, there is a small increase in energy use over time due to new development and economic growth. By comparison, in the central scenario, there is a near-total phase-out of fossil fuels due to the Heat in Buildings Regulation.

Figure 5-3. Phase 1 energy use by fuel type under the Baseline scenario

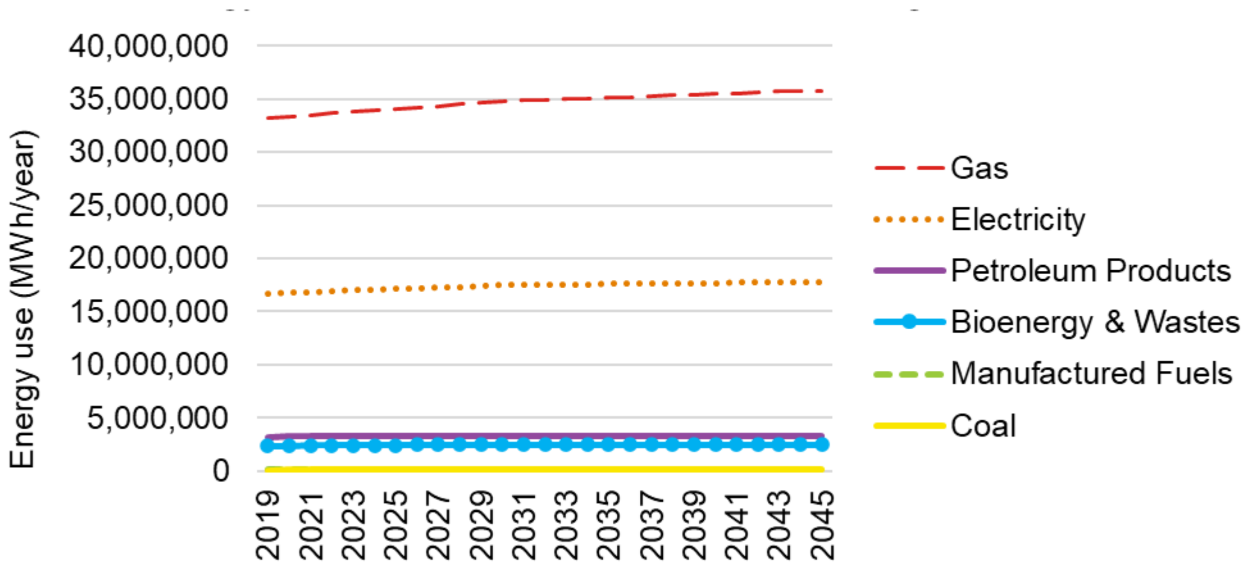
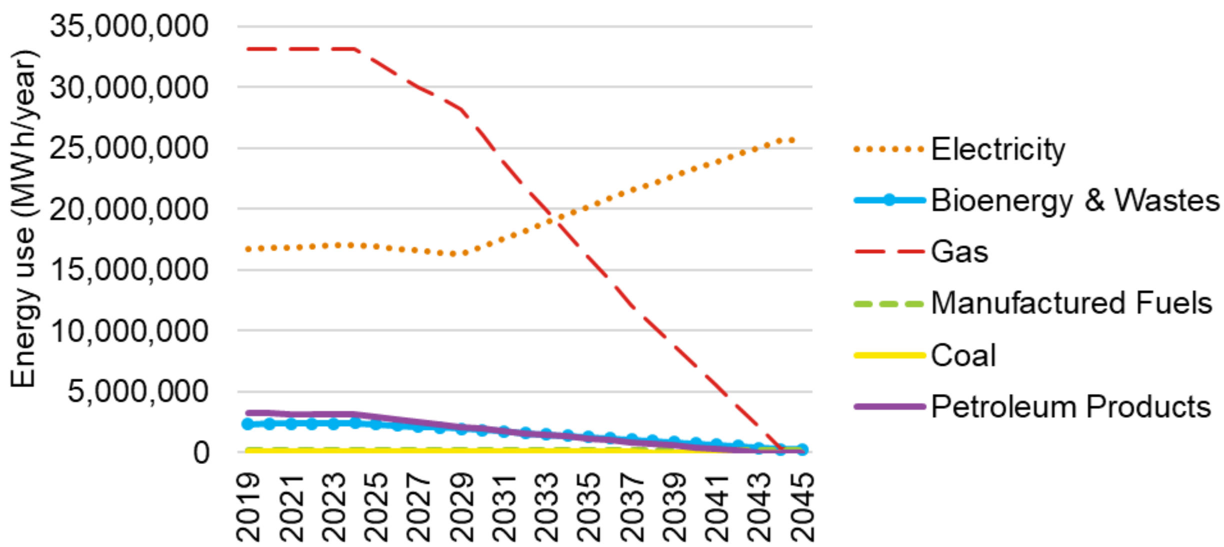


Figure 5-4. Phase 1 energy use by fuel type under the Central scenario.



Among the scenarios modelled, the main difference in energy use and emissions is due to assumptions about faster or slower uptake of retrofitting measures and zero emissions heating systems, as explained in the 'Sensitivities' section below, so the graphs have not been duplicated here.

Note: Potential impact of targets and capital funding schemes related to heat networks.

Heat networks offer the potential to deliver GHG emissions reductions in several ways, examples of which include:

- Providing an opportunity to utilise waste heat - e.g., from waste treatment or other industrial processes

- Plant may operate more efficiently when there is a high and consistent heat load (although note that in some circumstances this may be offset by heat loss along the distribution network)

From a logistical standpoint, they can also facilitate the transition to lower emission heat sources, because if buildings are connected to a communal or district heat supply, then in principle it may be possible to switch one centralised system to a low or zero carbon heat source, which could be easier than replacing individual heating systems.

However, the actual energy and emissions impacts depend heavily on multiple factors. From a GHG emissions standpoint, one of the key questions is what heating systems and fuel types are currently in use, and what they are being replaced by. Furthermore, heat networks or communal heating systems may be installed in new developments, in which case there may be no impact at all on existing sources of GHG emissions, and instead the effects might be captured under the New Build Heat Standard (NBHS) for new buildings.

It is understood that, although the Scottish Government has set targets for the amount of heat (in TWh) that will be supplied by heat networks in future, there is currently no detail on exactly what types of heat networks would be delivered, which makes a detailed assessment impossible.

These issues notwithstanding, to provide some general context for the potential impact of this target (and the available funding that has been allocated towards it), we have provided some high-level estimates.

Based on the assumptions set out in Appendix 3, achieving the 6 TWh target could reduce emissions by around 3% compared with a 2020 baseline of 40 MtCO_2e. The £300m in heat network funding could potentially contribute towards up to 20% of that target being met, leading to emissions reductions that are roughly equivalent to 0.2%-0.6% of total territorial emissions in 2020. This is likely to be an overestimate because it assumes that the heat networks will all use a zero direct emissions heat source. However, there is a much broader set of policies that will help to support and enable the development of heat networks in Scotland which have not been quantified.

These estimates are intended only to provide general context for the potential scale and direction of impacts from these policies, on the assumption that more detailed assessments would need to be carried out in future.

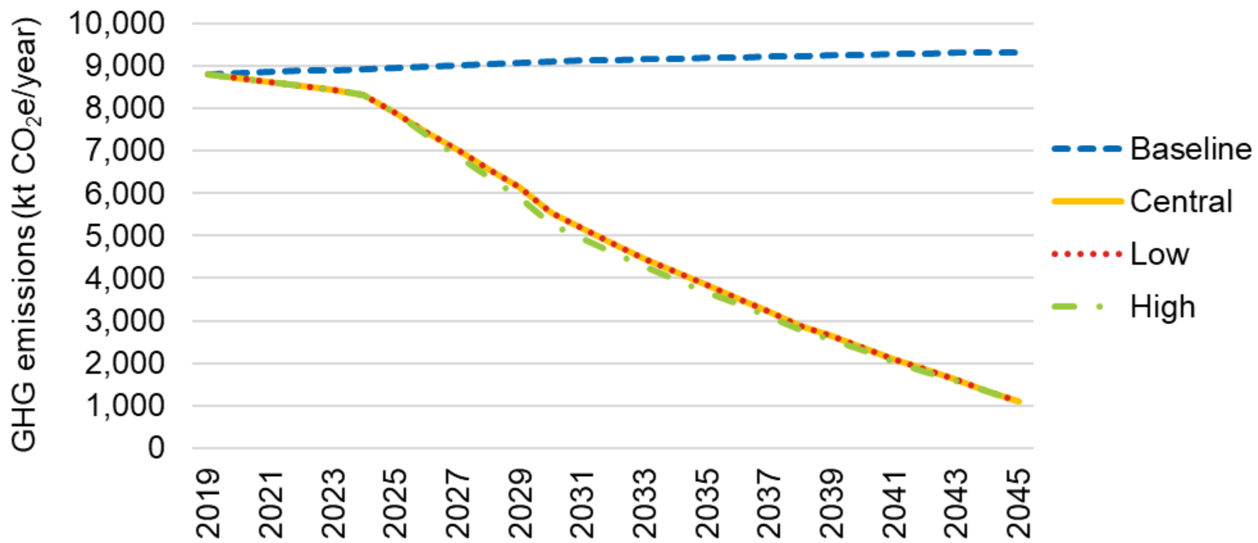
5.3.2 Phase 2 results

Results for the Buildings sector as a whole are shown below. In the Baseline scenario, emissions from buildings rise by 5-6% by 2045, from 8,802 ktCO_2e in 2019 to 9,303 ktCO_2e in 2045. In domestic buildings, the driver for this is population growth and an increase in the number of households, which is taken as a proxy for the number of new buildings constructed in that time period. In non-domestic buildings, the driver is economic growth, which is assumed to result in higher energy use, particularly in the commercial sector.

In all other scenarios, emissions from buildings fall by c. 84% by 2045.[20] The only difference between the decarbonisation scenarios is that cumulative emissions from the High Hydrogen scenario would be slightly lower than the others, due to the use of a gas/hydrogen blend as an interim decarbonisation measure. This is shown on the graph below. Note, “High” and “Low” in this instance refer to the High Hydrogen and Low Hydrogen scenarios.

As in Phase 1, in 2045 there would be some residual emissions from the building sector; these may include refrigerants and any wood or other fuels used as secondary heating.

Figure 5-5. Phase 2 emissions projections under the Hydrogen scenarios for the Buildings sector as a whole



Note: The results from the three growth scenarios are visibly almost indistinguishable from each other because of the small magnitude of differences between them.

In 2045 there would be some residual emissions from the Buildings sector; these may include refrigerants and any wood or other fuels used as secondary heating.

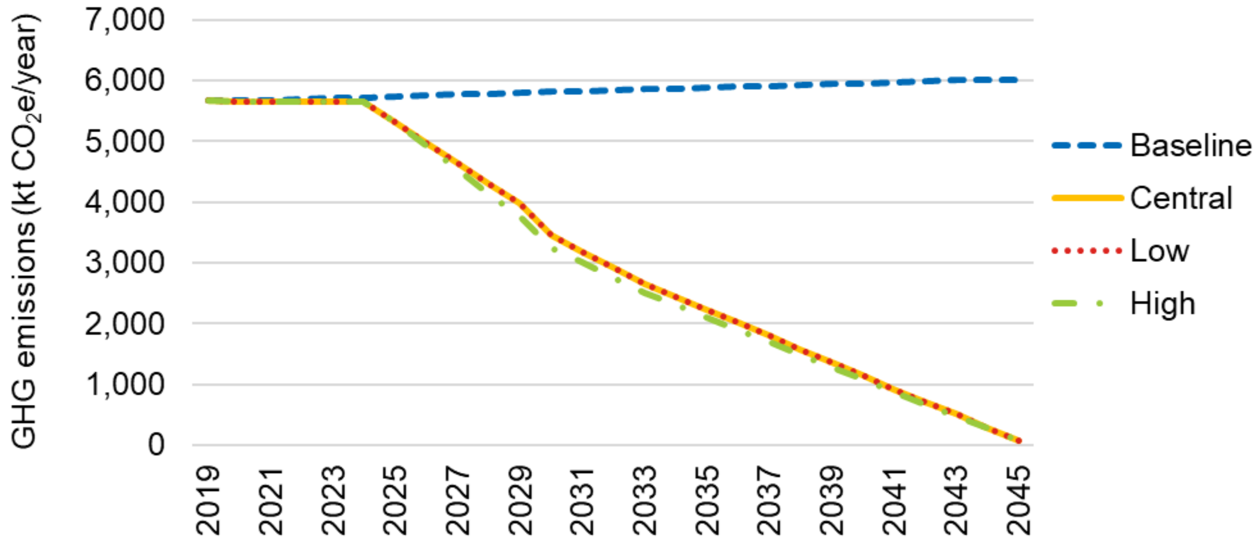
Further details relating to domestic and non-domestic buildings in Phase 2 are provided below.

Domestic buildings

Results for the domestic sector are shown below. Overall, emissions from the domestic sub-sector are shown to reduce to almost zero by 2045, which is due to the complete phase-out of fossil fuels and a switch to ZDEH.

[20] Because the results from most scenarios are the same, not all of them appear on the graph.

Figure 5-6. Phase 2 emissions projections under the Hydrogen scenarios for domestic buildings

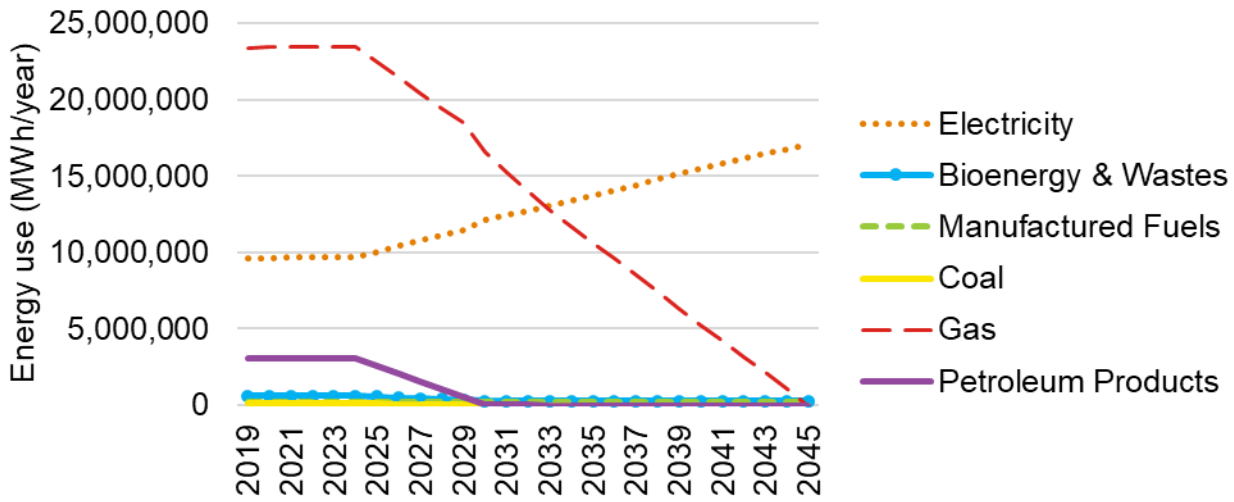


Note: The results from the three growth scenarios are visibly almost indistinguishable from each other because of the small magnitude of differences between them.

The initial slow reduction from 2019-2025 is due to energy efficiency upgrades (as noted previously, EPC ratings have been used as a proxy). This is followed by a steeper reduction in emissions in the second half of the decade as the Heat in Buildings regulations take effect. In combination, by 2030 these factors result in a c. 40% reduction in emissions from domestic buildings for all scenarios except the High Hydrogen scenario. In the High Hydrogen scenario, the reduction by 2030 is slightly higher, at 43% (however, since hydrogen is understood to be an interim measure prior to the widespread adoption of heat pumps, the results converge by 2045). From the 2030s onwards, the speed of decarbonisation is slightly slower as it is assumed that heating systems will be replaced at a rate closer to the natural replacement cycle. By 2045 there are very small residual emissions from the use of wood and other fuels used as secondary heating (e.g. domestic fireplaces).

The chart below illustrates how the above targets result in changes in energy use in dwellings.

Figure 5-7. Phase 2 energy use projections – Domestic Buildings

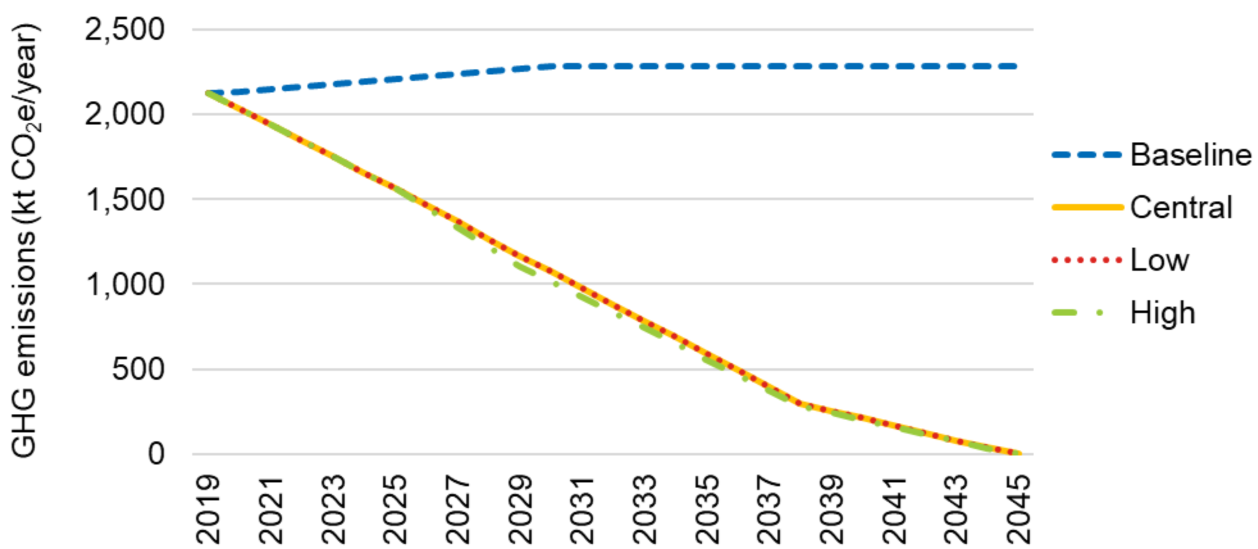


The trends in energy use and emissions are similar for each domestic sub-sector, with small variations due to the different EPC rating targets and associated backstop dates.

Non-domestic buildings

Results for the non-domestic buildings are shown below. The changes shown here are solely due to the reduction in fossil fuel consumption, which results in emissions decreasing by c. 45% by 2030 in most scenarios (c. 48% in the High Hydrogen scenario). This would achieve – and indeed exceed – the emissions intensity reduction target as well. By 2045, emissions from heat and electricity use in these buildings would reach net zero if all buildings switched to ZDEH, which has been modelled in the below graph.

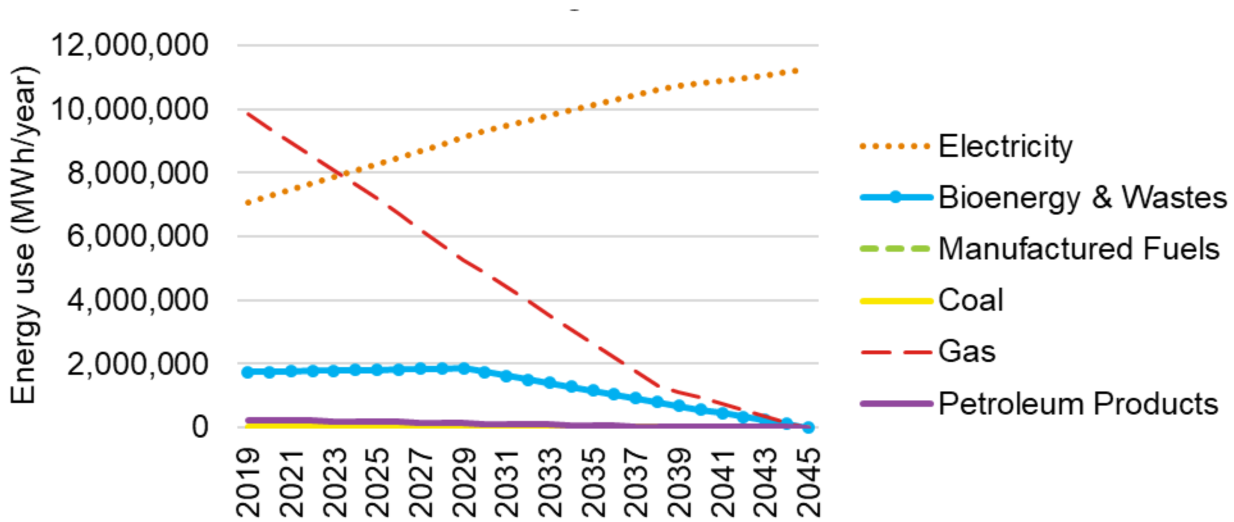
Figure 5-8. Phase 2 emissions projections under the Hydrogen scenarios for non-domestic buildings



Note: The results from the three growth scenarios are visibly almost indistinguishable from each other because of the small magnitude of differences between them.

This modelling assumes that the fossil fuel heat demand will shift to some other zero direct emissions energy vector such as electricity. However, the wording of the outcomes and targets does not specify which alternative fuel, technology, or other measures would be used to reduce fossil fuel heat demand to this extent, and in principle this could be achieved through different means.

Figure 5-9. Phase 2 energy use projections – Non-Domestic Buildings



Concluding points

Overall, the Phase 2 results support the findings of the Phase 1 modelling, which found that the most significant impacts are achieved from phasing out fossil fuel consumption in favour of zero direct emissions energy sources. The key mechanism for achieving this is through regulations aimed at replacing fossil fuel heating systems. The modelling also shows that cumulative emissions in the timeframe to 2045 depend not only on which mitigation measures are adopted, but also when they are adopted. For example, cumulative emissions in the domestic sector would be higher if the target of decarbonising more than 1 million homes by 2030 was reduced, postponed, or abandoned in favour of simply requiring all replacement heating systems to be ZDEH from the 2030s onwards.

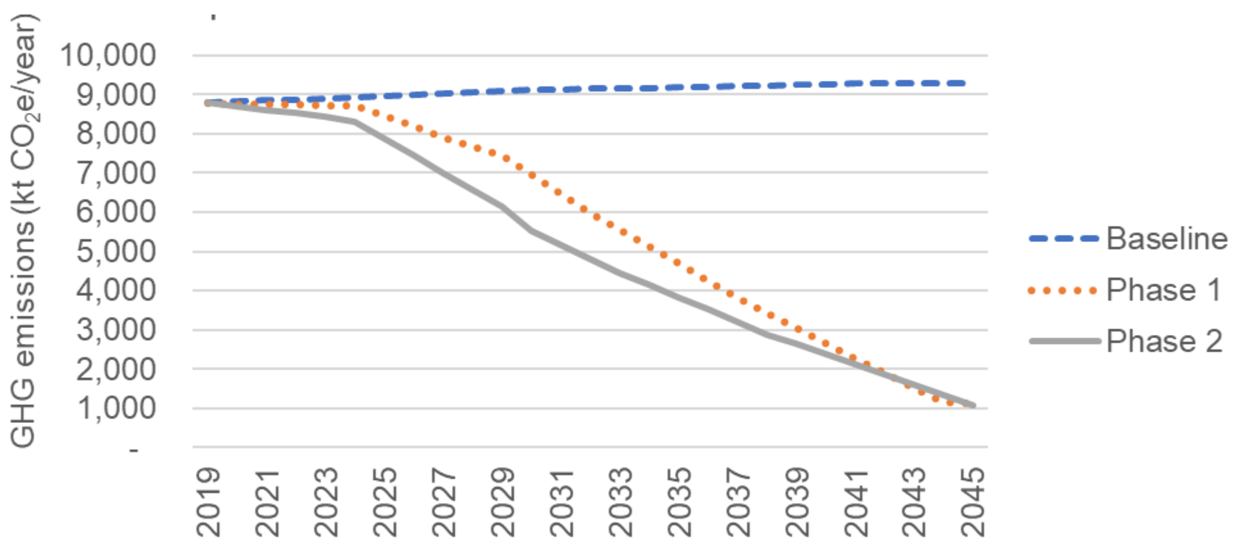
5.3.3 Comparison of Phases 1 & 2

Emissions projections from the Buildings sector for all scenarios in Phases 1 and 2 of the project are provided below in Table 5-10.

Table 5-10. Emission projections for the Buildings sector under the baseline and under modelled scenarios, for both Phase 1 and Phase 2 (in $ktCO_2e/year$)

Phase	Scenario	Emissions ($ktCO_2e/year$)						
		2019	2020	2025	2030	2035	2040	2045
n/a	**Baseline**	**8,802**	**8,820**	**8,967**	**9,114**	**9,186**	**9,259**	**9,303**
1	**Central Growth**	**8,772**	**8,748**	**8,448**	**6,951**	**4,678**	**2,660**	**1,140**
	High Growth	8,769	8,743	8,406	6,745	4,142	1,833	1,084
	Low Growth	8,774	8,753	8,491	7,157	5,213	3,509	2,209
	High Hydrogen	8,772	8,748	8,448	6,951	4,678	2,660	1,140
	Low Hydrogen	8,772	8,748	8,448	6,951	4,678	2,660	1,140
2	**Central Growth**	**8,802**	**8,703**	**7,887**	**5,539**	**3,835**	**2,369**	**1,086**
	High Growth	8,802	8,703	7,887	5,539	3,835	2,369	1,086
	Low Growth	8,802	8,703	7,887	5,539	3,835	2,369	1,086
	High Hydrogen	8,802	8,703	7,887	5,282	3,676	2,294	1,086
	Low Hydrogen	8,802	8,703	7,887	5,539	3,835	2,369	1,086

Figure 5-10. Differences in emissions from the Buildings sector between the modelling results from the Baseline scenario, and the Central scenarios in Phases 1 and 2



5.3.4 Emissions reduction by policy package (2032) – Phase 1 & 2

A comparison between the projected annual emission reduction by 2032 is provided below.

Table 5-11a. Emission reduction contributions (in $ktCO_2e$) of Buildings sector policy packages under model scenarios by 2032, with respect to the baseline

Policy Package	Emissions reductions by 2032 ($ktCO_2e$)									
	Phase 1					**Phase 2**				
	Central Growth	High Growth	Low Growth	High Hydrogen	Low Hydrogen	**Central Growth**	High Growth	Low Growth	High Hydrogen	Low Hydrogen
B1	-56	-56	-56	-56	-56	0	0	0	0	0
B2	-167	-201	-134	-167	-167	0	0	0	0	0
BX1 (Phase 2)	0	0	0	0	0	0	0	0	-414	0
BX2 (Phase 2)	0	0	0	0	0	-1,113	-1,113	-1,113	-1,048	-1,113
Individual Policy (Policy 6)	-119	-119	-119	-119	-119	-138	-138	-138	-138	-138
Individual Policy (Policy 8)	-1,767	-1,988	-1,547	-1,767	-1,767	-2,485	-2,485	-2,485	-2,381	-2,485
Individual Policy (Policy 1)	-30	-30	-30	-30	-30	0	0	0	0	0

Table 5-12b. Emission reduction contributions (in $ktCO_2e$) of Buildings sector policy packages under model scenarios by 2032, with respect to the baseline - continued

Policy Package	Emissions reductions by 2032 ($ktCO_2e$)									
	Phase 1					Phase 2				
	Central Growth	High Growth	Low Growth	High Hydrogen	Low Hydrogen	**Central Growth**	High Growth	Low Growth	High Hydrogen	Low Hydrogen
Individual Policy (Policy 2)	-26	-31	-20	-26	-26	0	0	0	0	0
Individual Policy (Policy 9)	-458	-550	-367	-458	-458	-597	-597	-597	-566	-597
Individual Policy (Policy 13)	-39	-39	-39	-39	-39	0	0	0	0	0
Individual Policy (Policy 21)	-496	-496	-496	-496	-496	0	0	0	0	0
Individual Policy (Policy 11c)	-4	-4	-4	-4	-4	0	0	0	0	0
Total tables 5.7a and 5.7b	**-3,163**	**-3,513**	**-2,813**	**-3,163**	**-3,163**	**-4,332**	**-4,332**	**-4,332**	**-4,548**	**-4,332**

5.4 Uncertainties

A formal uncertainty analysis has not been carried out, but some commentary on key issues and the potential scale of uncertainty associated with these estimates is provided below.

- Disaggregation of energy use by sub-sector: For domestic buildings, energy use has been disaggregated based on split of tenancies, which assumes that all tenancies consume the same amount of fuel on average. In practice, this varies by tenancy. This would have a relatively small impact on the results for each domestic sub-sector but will not impact the results for the domestic buildings sector as a whole. For non-domestic buildings, the disaggregation of energy use is more uncertain. It is difficult to estimate the impact this would have at a sub-sector level, but again the impact is likely to be lower when considering non-domestic buildings as a whole.
- Impact of growth in the Baseline scenario: Assuming that new buildings will be highly efficient and fitted with zero direct emission heating systems, variation in new development rates would have minimal impact on the results. However, year-on-year variation associated with economic changes, energy prices, or weather could impact results by roughly ±10%.
- Impact of capital funding schemes, ECO, RHI, etc.: The actual energy savings from these types of installations varies significantly between properties, potentially by ±50%. In some instances, occupants may actually use more energy following retrofitting measures (known as the take-back effect). Furthermore, historically it has been the case that not all available funding is actually deployed, so the impact on energy use may have been overestimated on that basis. However, the overall impact of these schemes is small, so this will not have a major impact on the overall results.
- Impact of retrofitting and minimum EPC rating targets: The scale of improvement from retrofitting has been modelled as 13-15% reduction in space heating demand depending on the sub-sector. This assumes that a proportion of buildings do not meet the minimum EPC rating target. Increasing the proportion that do meet the target could result in reductions of up to 20%. However, a conservative assumption has been made to reflect uncertainties in the funding and regulatory approach. In a worst-case scenario, where there continues to be a small uptake of only the most cost-effective measures, the reduction in space heating demand could be much lower than what has been modelled.
- Impact of switching to zero direct emission heating systems: There are three significant sources of uncertainty, all of which could have a major impact on the emissions projections for buildings since this is the key sensitivity in the model (see ‘Sensitivities’ section below).
    - The assumed rate of uptake of zero direct emission heating systems – If this is lower than anticipated, that would have a significant impact on the total results for this sector. Recognising that it is not yet clear how the Heat in Buildings Regulation would be implemented or enforced, uptake could be – in theory, based on current rates of heat pump installations – 90% lower than anticipated. (It cannot be higher because we have assumed that all properties would switch by 2045 at the latest.)
    - Which heating fuels are displaced, and what alternative energy sources they are displaced by – Although not necessarily captured in the model due to the

boundary of the analysis, it is worth acknowledging that some ZDEH systems may still result in GHG emissions elsewhere in the energy system. Depending on the source of electricity, hydrogen, biodiesel, etc., there could be emissions that are not reflected in the current model, which assumes all fossil fuels in buildings will switch to decarbonised electricity. [21]

- The relative efficiency of the original heating systems versus the new heating systems – This impacts energy demand, although it does not necessarily impact emissions if one assumes that electricity is zero carbon. The scale of uncertainty here is considerable. For example, direct electric heating could be classed as a zero direct emissions heating system, but would use roughly three times as much electricity as a heat pump with a COP of 3.0. So, the projected energy demands in buildings by 2045 could be up to 300% of the projected figure in the model. Potentially, this could be even higher if green hydrogen was used to heat buildings, because it uses much more renewable electricity due to lower conversion efficiencies.

The following points only apply to the modelling carried out under Phase 2:

- Blending "green gas" into the gas network: At this stage, the blend of hydrogen and biomethane is uncertain, as is the method of production of hydrogen. These would both have an impact on the total emissions reduction at the whole-systems level that is achieved through this measure. For example, if the hydrogen is not "green hydrogen", the emissions reduction that is achieved through this measure would decrease.
- Reducing fossil fuel consumption in the service sector: As stated previously, the reduction has been modelled based on an assumed switch to heat pumps, but the wording of the target is not specific and in principle this could be achieved through other means. The modelled GHG emissions would not change significantly. However, the modelled energy use in the service sector is uncertain.

5.5 Sensitivities

The projected growth in domestic and non-domestic energy use in the Baseline scenario is small, although not insignificant considering that any increase in emissions will make net zero harder to achieve. By 2045, this would increase emissions within this sector by around 6% relative to 2019.

The impact of the capital funding schemes is small, reflecting that they are targeted at a small number of households with the aim of addressing fuel poverty and achieving emissions reductions, and mostly serve to mitigate the increase in emissions from buildings that would otherwise occur due to new development and economic growth. This is because the number of measures installed is very low compared with the total number of buildings. Historically, many of these schemes have also included upgrades that only

[21] While it is assumed that the electricity grid will largely decarbonise over time, the rate and scale of decarbonisation is uncertain. Future trajectories for grid decarbonisation are provided in Figure 3.4.b in the CCC report, *'The Sixth Carbon Budget: The UK's path to Net Zero'* (2020). Available at: https://www.theccc.org.uk/publication/sixth-carbon-budget

have a small impact on energy consumption, such as replacing old boilers with new ones, or installing smart meters.

If and when the building stock as a whole is retrofitted to higher energy efficiency standards, this would have a larger impact. (As noted previously, we have used EPC ratings as a proxy for fabric efficiency, recognising that there are limitations to this approach.) Depending on the sub-sector in question, this would reduce heating demands within each sub-sector by roughly 13-15%.

By far the most impactful policy from an energy demand and emissions standpoint is the Heat in Buildings Regulation, which is assumed to result in the near-total phase-out of fossil fuel use in the Buildings sector.[22] Within this, the key variables from a whole-systems perspective are (1) the difference in carbon intensity of fossil fuels versus grid electricity and (2) the difference in efficiency between boilers, direct electric heating, and heat pumps. In principle, the same level of overall territorial emissions reduction could be achieved by using electric boilers or direct electric heating systems, assuming that all buildings still switch to zero carbon electricity; however, the heat pump performance is what drives the biggest reduction in energy demand for the sector.

[22] Demand reduction measures are crucially important for a variety of reasons, but without deep energy retrofits of the entire building stock will still show less of an impact on GHG emissions than the switch to ZDEH. For more information on the importance of demand reduction, refer to CREDS, *'The role of energy demand reduction in achieving net-zero in the UK'* (2021). Available at: https://www.creds.ac.uk/wp-content/uploads/CREDS-Role-of-energy-demand-report-2021.pdf

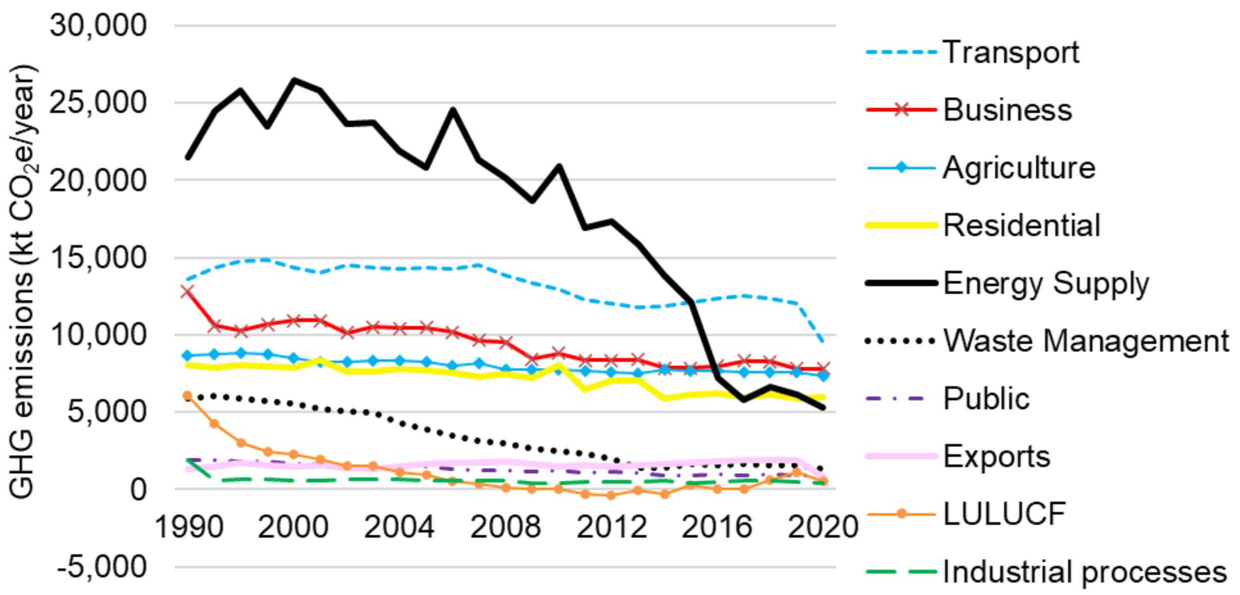
6. Electricity sector

6.1 Sector Overview

6.1.1 Sector Background

The Electricity sector has seen significantly greater progress with decarbonisation, through closure of fossil fuel power and switching to renewables, than any other sector, as illustrated below. This is primarily due to the phase-out of coal to generate electricity, in favour of gas and renewable energy technologies.

Figure 6-1. Historical GHG emissions for Scotland, by sector, from 1990-2020



Policy change here is aimed not so much at transformation (which has happened) but expansion to support electrification of vehicles, space conditioning, and hydrogen production. Changes in electricity price through external geopolitical events, as much as through policy, are already making further renewables investments very attractive, and the cost-effectiveness of wind, solar and other marine technologies is improving all the time.

The CCPu includes 23 electricity policies, of which only one is proposed for a full assessment - the Offshore Wind Policy Statement, which includes a range of actions that are designed to support the development of between 8 and 11 GW of offshore wind. The additional electricity generated by the growth of offshore wind is not used to estimate the amount of electricity generation offset from power plants that release emissions. The other policies are not assessed.

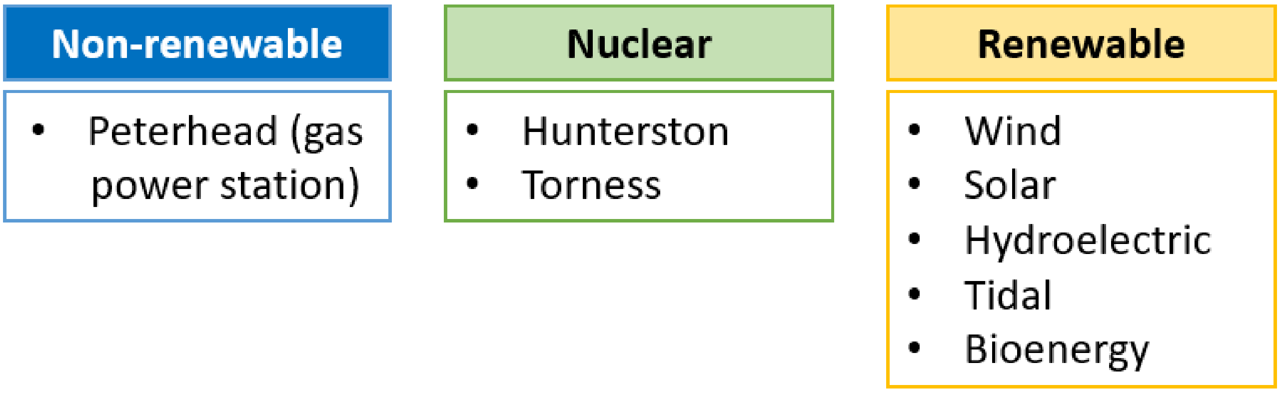
6.1.2 Subsectors Considered

The Electricity sector's capacity was disaggregated into the following subsectors:

- Non-renewable;
- Nuclear; and
- Renewable.

The structure of the Electricity sector and technology supplying capacity, as modelled in this study, is shown in Figure 6-2 below. This study has a baseline of 2019 with the latest forecast year of 2032 as such all types of technology contributing capacity over this period have been included.

Figure 6-2: A visualisation of the disaggregation of the Electricity sector



6.1.3 Data Sources

The main data sources used to undertake the assessment of the Electricity sector in Scotland are detailed in Table 6-1 below.

Table 6-1: A summary of the different data sources used in the assessment of the Electricity sector.

Purpose	Data used	Comment
GHG inventory for Scotland	**UK National Atmospheric Emissions Inventory (UK NAEI)**	GHG inventory for Scotland needed to estimate impacts of policies on emissions from all electrical generation technology including bioenergy The bioenergy emission factors are only based on scope 1 emissions.
Capacity and electricity generation for Scotland	**Scottish Energy Statistics (gov.scot and BEIS).** BEIS regional data are published in Energy Trends together with Quarterly Estimates**.**	Provides capacity and electricity generation for different technologies. This is used to establish what the actual baseline (2019) electricity generation is for Scotland.
Future year capacity and electricity generation without CCPu policies	**BEIS: Renewable energy planning database (REPD)**	Provides capacity growth for different technologies. This is used to forecast what the future baseline (2045) electricity generation is for Scotland. The methodology used to forecast future energy generation is provided in the section 'Underlying drivers of energy and emissions'.
Establish load factors for proposed renewable capacity committed in planning and in CCPu policies	**BEIS: Energy Trends (published 31/03/2022)**	Used to establish load factors, which refer to the percentage of electricity generation out of the maximum annual potential. The methodology used to forecast future energy generation is provided in the section 'Underlying drivers of energy and emissions' and 'policy measures'.

6.1.4 Underlying Drivers of Electricity & Emissions

The underlying drivers of electricity demand are related to energy use in buildings and industry, transport electrification, and associated energy efficiency. The drivers of emissions associated with electricity supply is the technology used for generation in Scotland. There is a trend towards renewable capacity in Scotland, with the decommissioning of the Hunterston (2022) and Torness (2028) Nuclear power stations and Lerwick Power station (2024). Further to this, emergence of carbon capture and storage (CCS) technologies will reduce greenhouse gas emission rates with a CCS gas power station which could replace the existing Peterhead gas power station in 2027 at the earliest. The capacity of renewables in the planning pipeline more than offsets the lost capacity of decommissioning the Peterhead gas power station. Whilst non-renewable capacity is offset by renewables, due to the intermittent nature of renewables there is a risk that capacity – including system balancing and wider system security – will need to be met by non-renewable technologies such as Peterhead CCS. DUKES UK power station records[23] were used to establish the loss of electrical capacity associated with decommissioning power plants and BEIS' renewable energy planning database (REPD)[24] was used to forecast capacity that has received planning permission. (Note that not all technologies that are listed in the REPD as having obtained planning permission will necessarily become operational.) In the BEIS renewable energy planning database all renewable technologies awarded planning permission, but not operational in 2019 have been included in the future generation. It was assumed that the difference between electricity generation in 2019 and future generation would have linear growth until 2032.

The following assumptions were made when forecasting the energy generation from different technologies:

- The 2019 MWh generated per GW capacity of all power station types was assumed to remain constant.
- Emissions from biomass were considered at the point of combustion rather than in terms of net lifecycle emissions.
- The load factors for additional capacity of renewable technologies, i.e. those that will be added in future years, were based on the 10-year average load factors between 2012-2021 for technologies that were awarded planning permission as reported in the BEIS Energy Trends[25] publication. These are set out below:
    - Offshore wind: 36%
    - Onshore wind: 26%
    - Tidal energy: 4%
    - Hydroelectric: 36%
- The electricity generation potential of Peterhead and associated emission factors were taken from the Environmental Statement.

[23] https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes
[24] https://www.gov.uk/government/publications/renewable-energy-planning-database-monthly-extract
[25] https://www.gov.uk/government/statistics/energy-trends-section-6-renewables

6.2 Policy Measures and Outcomes Modelled

6.2.1 Phase 1 – Policy Measures

For the Electricity sector there were a total of 23 policies to be assessed. The policies were grouped into 3 packages covering similar themes, to allow policies targeting the same measures to be assessed together and thus ensure interactions between similar policies/proposals were captured. For example, there are multiple policies with targets for renewable energy generation from specific technologies and in general, all of which will have a combined effect on Scottish Government's ambitions for renewable energy generation. Grouping policies into themes, as below, allows such interactions to be identified and addressed. Note that many of the policies were deemed unquantifiable and screened out of the assessment. A total of three policies were compiled into two packages, but two of these policies were deemed to not have a quantifiable impact on the Electricity sector (either because no target was set, or because the impacts are expected to be on demand sectors). Table 6-2 below shows the packaging of policies into key themes, and the quantifiable targets informing the assessment. Only the offshore wind policy has been taken forward.

Table 6-2: A summary of CCPu policies for the Electricity sector

Theme	Quantifiable targets	Relevant policies / strategies / actions
Renewable electricity in Scotland		
Policies not assessed	**Targets:** • 50% renewable energy consumption across electricity, heat and transport. • 1 to 2 GW of renewable energy in local community ownership.	• Renewable energy consumed across electricity, heat and transport. • Focus on developing local energy projects
Policies assessed	**Targets:** • 8 to 11 GW of offshore wind capacity.	• Offshore wind policy statement
Scotland's Renewable electricity exports		
Energy efficiency policies (not assessed)	• n/a, no target set.	• Reform the CFD mechanisms to better capture the economic benefit and total value.

6.2.2 Phase 2 – Outcomes

Representatives of the Scottish Government and Ricardo Energy & Environment (REE) discussed options for modelling additional outcomes and targets as part of Phase 2 of the Provision of Emissions Projections project during a workshop.

Some of the policies modelled as part of Phase 1 are expected to contribute to the targets that were modelled in Phase 2. The timing of the new Carbon Capture and Storage gas power station at Peterhead coming online was discussed and amendments to renewable and non-renewable generation load factors were discussed and agreed.

Table 6-3 below shows the additional impacts that were considered during Phase 2. These are predominantly based on the policy outcomes and targets listed in the Climate Change Plan Monitoring Report 2022, although they have been modified to reflect subsequent discussions between Ricardo and Scottish Government.

Table 6-3. Additional impacts modelled in the Electricity sector

Outcome	Additional impacts modelled
1. The electricity system will be powered by a high penetration of renewables, aided by a range of flexible and responsive technologies.	The proposed CCS at Peterhead was previously modelled as coming online in 2033. This has now been modelled as coming online in 2027. 10-year average load factor changed to reflect BEIS' projected load factors in electricity generation costs[26].
2. Scotland's electricity supply is secure and flexible, with a system robust against fluctuations and interruptions to supply.	Not quantifiable
3. Scotland secures maximum economic benefit from the continued investment and growth in electricity generation capacity and support for the new and innovative technologies which will deliver our decarbonisation goals.	Not quantifiable

During the sector workshop, other fossil fuel plants generating electricity were discussed and consideration was given to how emissions could be reduced further, in particular offsetting diesel generators with battery storage for emergency back-up power and grid stabilisation. After an internal review, it was not considered feasible for a sufficiently accurate fossil fuel generation displacement calculation to be included as part of this project. The reasons why we reached this conclusion are related to a lack of data on:

- The round-trip efficiency of battery storage.
- Whether the sites will be completely charged by renewable energy.

[26] Department of Energy Security and Net Zero, *'BEIS Electricity Generation Costs'* (2020). Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020

- The purpose of the battery storage sites (Grid Balancing, Time Shifting, Backup Power, Black Start) and the nature of proposed grid service contracts (response/reserve and firm/optional).

6.2.3 Summary of Policy Packages

The table below indicates which policies were found to have the biggest potential impact within each package, which policies overlap with (or reinforce) each other, and which policies act as supporting measures.[27]

Electrification, which is key to reducing emissions from the Buildings, Transport and Industry sectors in particular, will rely on access to a secure, reliable source of renewable electricity. The Electricity sector policies in the CCPu can therefore be said to reduce emissions from multiple sectors indirectly, inasmuch as they minimise the need to generate electricity using unabated fossil fuels. The largest impacts in this sector that have been assessed in this study are associated with (a) to the Peterhead gas power station being decommissioned and replaced with a carbon capture, storage and utilisation gas power station and (b) additional offshore wind capacity.

Table 6-4a. Policy packages for the Electricity sector – E0 Additional planned changes

Policy	Categorisation
N/A - this package covers planned changes to the electricity generation mix not covered in CCPu policies	N/A

[27] The following descriptions have been used:

- **Key policies** are those that are expected to have the largest direct, tangible impacts on emissions, relative to others within each package.
- **Supporting measures** are those that will not have a direct, quantifiable impact on emissions, but may create an enabling environment or facilitate development of further policies/actions that will have a direct impact.
- **Overlapping/reinforcing measures** are those that interact with (and often contribute to the same activity impacts as) other policies - modelling these policies separately without consideration of interactions with other policies would incur double counting of emissions reductions.

Table 6-5b. Policy packages for the Electricity sector – E1 Scaling Up Renewable Electricity, policies

Policy	Categorisation
Policy 1: Support the development of a wide range of renewable technologies by addressing current and future challenges, including market and policy barriers.	Supporting measure
Policy 2: Support improvements to electricity generation and network asset management, including network charging and access arrangements that encourage the deployment and viability of renewables projects in Scotland.	Overlapping/reinforcing measure
Policy 3: Publish a revised and updated Energy Strategy, reflecting our commitment to net zero and key decisions on the pathways to take us there.	Overlapping/reinforcing measure
Policy 4: Develop and publish a Hydrogen Policy Statement by the end of 2020, followed by a Hydrogen Action Plan during 2021.	Supporting measure
Policy 5: A new renewable, all energy consumption target of 50% by 2030, covering electricity, heat and transport.	Overlapping/reinforcing measure

Table 6-6c. Policy packages for the Electricity sector – E1 Scaling Up Renewable Electricity, proposals

Policy	Categorisation
Proposal 1: Introduce a new framework of support for energy technology innovation, delivering a step change in emerging technologies funding to support the innovation and commercialisation of renewable energy generation, storage and supply.	Supporting measure
Proposal 2: Renewed focus on developing local energy projects and models, including through CARES, supporting the achievement of 1GW and 2GW of renewable energy being in Local Community ownership by 2020 and 2030.	Supporting measure
Proposal 3: We will carry out detailed research, development and analysis during 2021 to improve our understanding of the potential to deliver negative emissions from the electricity sector.	Supporting measure
Proposal 4: We will continue to review our energy consenting processes, making further improvements and efficiencies where possible, and seeking to reduce determination timescales for complex electricity generation and network infrastructure applications.	Overlapping/reinforcing measure
Proposal 5: We will deliver the actions from our Offshore Wind Policy Statement, published in October. These actions, ranging from support for supply chain, planning, innovation and skills, will support the development of between 8 and 11 GW off offshore wind capacity by 2030.	Key policy
Proposal 6: Accelerate our work with aviation, energy and other stakeholders to ensure that all radars are wind turbine tolerant/neutral during the coming decade.	Supporting measure
Proposal 7: Review and publish an updated Electricity Generation Policy Statement ahead of the next Climate Change Plan.	Supporting measure

6.2.4 Variation across scenarios

Economic growth is assumed to dictate how much offshore wind can be delivered (the only quantifable policy for the electricity sector). As the offshore wind farm policy aims to introduce between 8 to 11 GW of electricity capacity by 2030, 9.5GW was assumed to be achieved in the central scenario, the maximum of 11GW was assumed to be achieved under high growth, and the minimum of 8GW was assumed to be achieved under the low growth scenario. Hydrogen scenarios were not explored for this sector. It should be noted that the offshore wind capacity that has been awarded planning permission between 2019 and 2022 has not been discounted from the additional GW capacity associated with this policy. Consequently, there is a chance that the impact of the offshore wind farm policy is over-represented based on the level of ambition set out above.[28]

6.3 Emissions Projections

6.3.1 Phase 1 results

Under all scenarios the quantifiable CCPu offshore windfarm policy has no impact on GHG emissions in the modelled implementation year and all subsequent years (Figure 6-3). However, there is a slight dip in emissions in 2024 and a substantial decrease in 2033 in the central, low and high scenarios. This is due to existing commitments to decarbonising Scotland's energy supply and that the additional offshore windfarms already committed in planning provide sufficient capacity for forecasted energy demands. The decarbonisation plans are:

- The diesel power station on Lerwick is being moved to becoming a backup station in 2024 and for supply to be replaced with a connection to the national grid.
- The gas power station at Peterhead is to be replaced with a CCS gas power station in 2027. However, for consistency with the other CCS measures this has been introduced in 2033.

Decommissioning of the diesel power station in Lerwick and replacement of the Peterhead gas power station with a CCS gas power station are committed policies and should appear in the baseline. However, model configuration means that changes to electricity generation and emissions can only be reflected in the scenarios. For clarity on the implications of this model configuration on results, the CO_2e emission decrease in 2024 and the substantial decrease in 2033 are associated with the CCS power station replacement at Peterhead, the aforementioned CO_2e decrease is not associated with the implementation of the offshore windfarm policy (the only quantitatively assessed CCPu electricity policy). (Note: the implementation date of the CCS retrofit at Peterhead is modified to be 2027 in the refined Phase 2 modelling – see Section 6.2.2).

The impact of the CCPu offshore wind farm policy is very clear when comparing the baseline and central scenario energy use charts in Figure 6-4 and Figure 6-5.

The central scenario will result in approximately 14 million additional MWh in electricity by 2045, compared to the baseline. The low and high scenario also increase renewables' MWh generated by 10 and 19 million MWh, respectively. The additional offshore capacity (3.9 GW) granted planning permission between 2019 and 2022 have not been discounted from the GW capacity introduced by the CCPu offshore wind farm policy, this may be discounted in reality, consequently the GW capacity from this policy may be an overestimate (ranging from 4.1 to 7.1 GW).

[28] Since the CCPu and Offshore Wind Policy Statement were published, the level of Industry ambition on wind energy has increased significantly. As part of the ScotWind project, the Crown Estate Scotland offered large areas of seabed for leasing, which could potentially deliver more than 27 GW of offshore wind capacity. Therefore, the targets that have been modelled in this study may underestimate future wind energy deployment.

Figure 6-3: Phase 1 emissions projections under all modelled scenarios for the Electricity sector as a whole

Note: The results from the three growth scenarios are visibly almost indistinguishable from each other because of the small magnitude of differences between them.

Figure 6-4: All energy use forecasts for the Baseline scenario

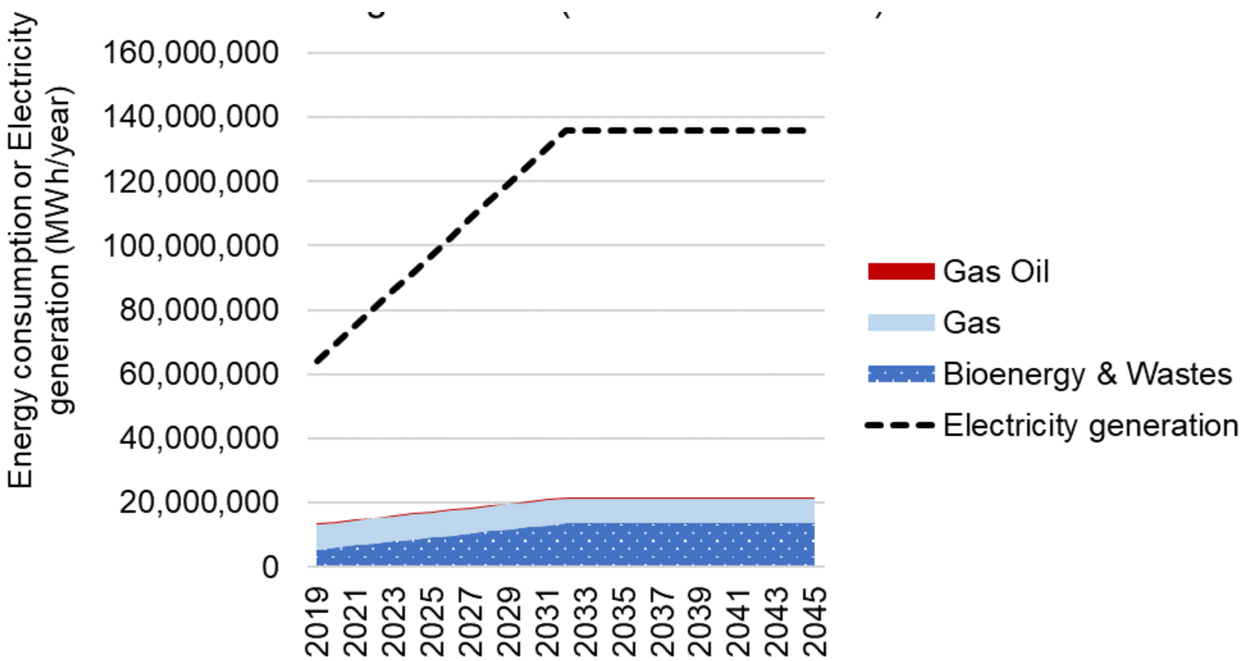
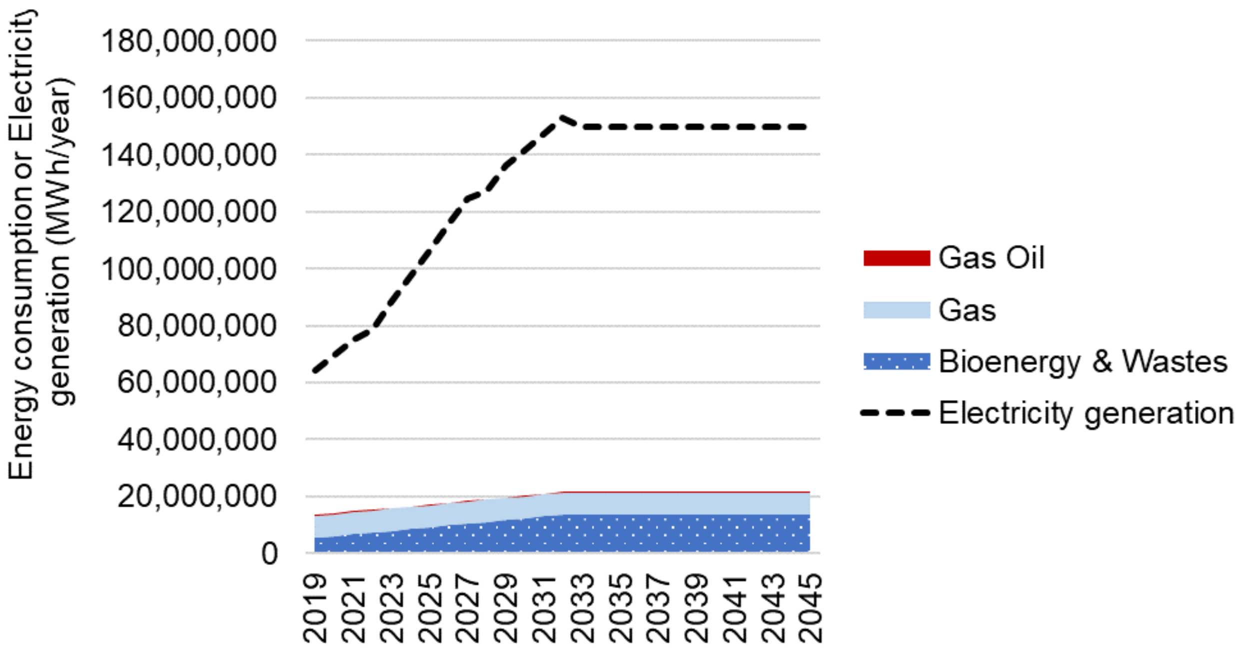


Figure 6-5: All energy use forecasts for the Central scenario under Phase 1.



Note: In Figure 6-4 and Figure 6-5 the gap between electricity consumption and electricity generation is accounted for by renewable electricity generation (not associated with a fuel).

6.3.2 Phase 2 results

Results for the Electricity sector are shown in Figure 6-6 below. In the baseline scenario, emissions from electricity rise by 26% by 2045, from 2,032 kt CO_2e in 2019 to approximately 2,570 ktCO_2e. The main driver for the increase in CO_2 is a 2035 bioenergy and waste source projected load factor of 80.7% derived from BEIS. The baseline energy use is based on DUKES 2019[29] energy statistics from biomass. Energy use is substantially increased by the projected load factor of 80.7% factor (compared to previous load factors considered/modelled) which takes measured bioenergy and waste energy use from 5,486 GWh in 2019 to 13,624 in 2045. The impact of the projected load factor causes an increase of 498 kt CO_2e emissions between 2019 to 2032.

Phase 1 baseline (2019) electricity generation was assumed constant up to the target year (2032) as there was no growth in bioenergy electrical capacity or load factor. However, in phase 2 it was assumed that there would be growth between baseline bioenergy electricity generation to the target year, as the load factor was forecast to increase from the observed value of 54.4% in 2019, to 80.7% using BEIS' projected load factor in 2032. However, there was no growth in bioenergy electrical capacity. The projected load factor was applied to total bioenergy electrical capacity which caused an increase in CO_2 emissions. It should be noted this approach deviates from Scottish Government's of applying historical observed load factors to existing plant in future years, as this study has

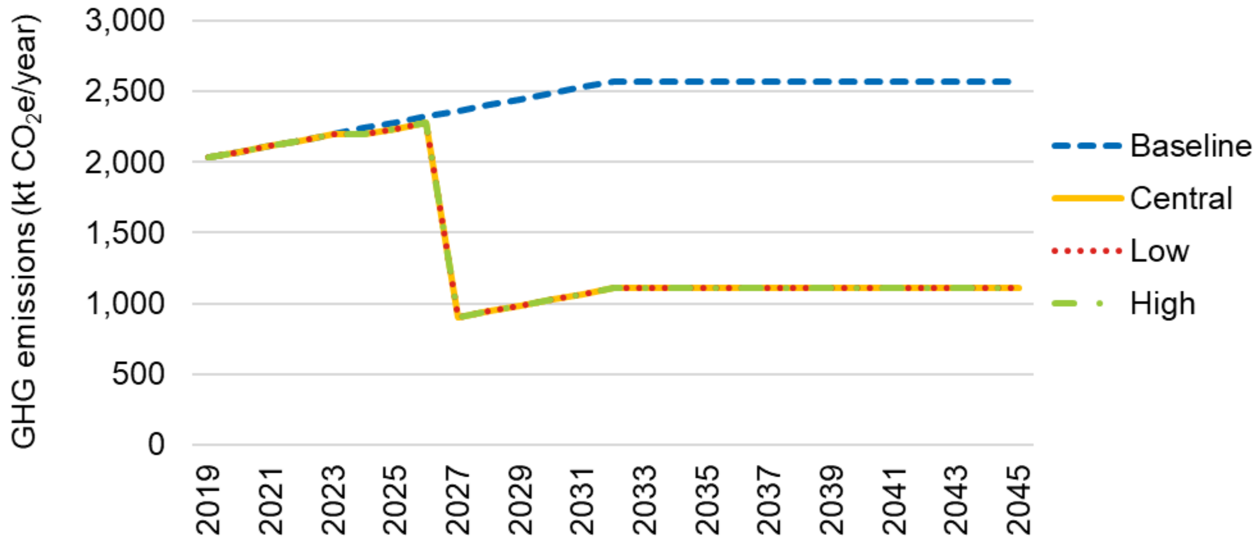
[29] Department for Business, Energy and Industrial Strategy, *'Digest of UK Energy Statistics (DUKES)'* (2019)'. Available at: https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2019

assumed that existing plant will reach BEIS' projected load factors. The forecast emissions from bioenergy do not account for forecasted CCS capabilities detailed in Section 10.

There is a slight decrease in carbon emissions in the low, central and high scenarios in 2024 as a result of the Lerwick diesel power station being decommissioned. This featured in Phase 1 and **is not** a decrease in carbon emission introduced in Phase 2.

The impact of the additional measures can be seen in 2027 when the new Peterhead CCS plant comes online and drops carbon emissions in the Electricity sector from 2,276 to 900 kt CO_2e. The transition to CCS at Peterhead reduces carbon emissions by 1,376 kt CO_2e.

Figure 6-6. Phase 2 emission projections for the Electricity sector



Note: The results from the three growth scenarios are visibly almost indistinguishable from each other because of the small magnitude of differences between them.

Overall, the Phase 2 results support the findings of the Phase 1 modelling, which found that the most significant impacts are achieved by introducing a new CCS gas turbine plant at Peterhead. The decrease in carbon emissions with only the CCS online at Peterhead is 1,376 kt CO_2e per annum. With the CCS replacement at Peterhead coming online in 2027 rather than 2033, there will be a cumulative removal of 8,256 kt (1,376 x 6) CO_2e between 2027 and 2033. However, BEIS' projected electricity cost load factors have resulted in a substantial increase in per annum electricity generation and carbon emission compared to the Phase 1 methodology of extrapolating 2019 biomass electricity generation and carbon emissions.

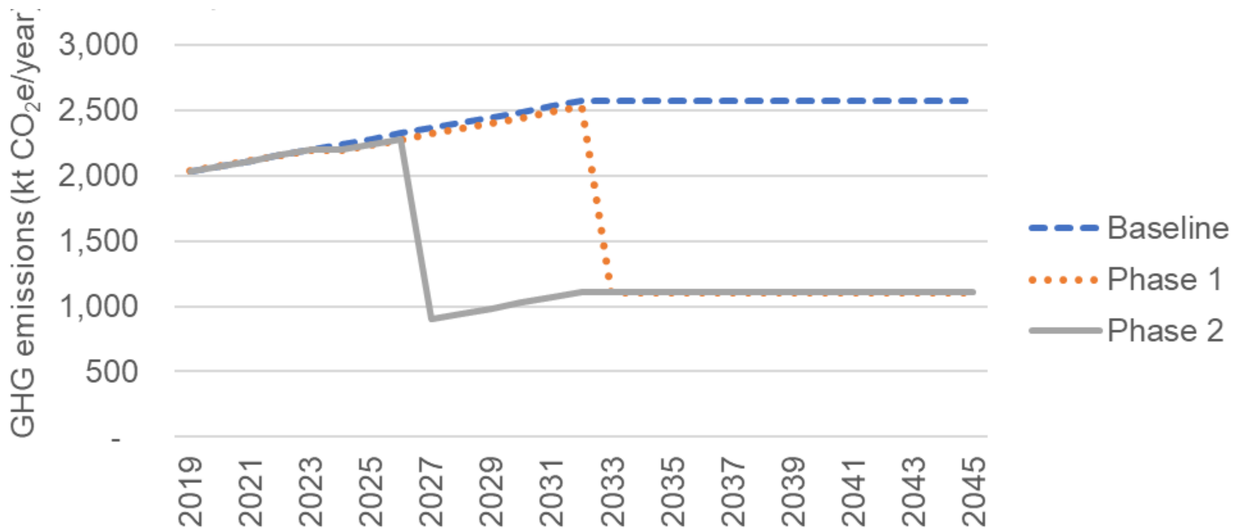
6.3.3 Comparison of Phases 1 & 2

Emissions projections from the Electricity sector for all scenarios in Phases 1 and 2 of the project are provided in Table 6-7, below.

Table 6-7. Emission projections for the Electricity sector under the baseline and under modelled scenarios, for both Phase 1 and Phase 2 (in $ktCO_2e$)

Phase	Scenario	Emissions ($ktCO_2e$)						
		2019	2020	2025	2030	2035	2040	2045
n/a	**Baseline**	**2,032**	**2,072**	**2,279**	**2,487**	**2,570**	**2,570**	**2,570**
1	**Central Growth**	**2,032**	**2,072**	**2,234**	**2,442**	**1,108**	**1,108**	**1,108**
	High Growth	2,032	2,072	2,234	2,442	1,108	1,108	1,108
	Low Growth	2,032	2,072	2,234	2,442	1,108	1,108	1,108
2	**Central Growth**	**2,032**	**2,072**	**2,234**	**1,025**	**1,108**	**1,108**	**1,108**
	High Growth	2,032	2,072	2,234	1,025	1,108	1,108	1,108
	Low Growth	2,032	2,072	2,234	1,025	1,108	1,108	1,108

Figure 6-7 . Differences in emissions from the Electricity sector between the modelling results from the Baseline scenario, and the Central scenarios in Phases 1 and 2



6.3.4 Emissions reduction by policy package (2032) – Phase 1 & 2

For other sectors, there is a breakdown of emissions into policy groups in the Phase 2 assessment. In the Electricity sector, however, the only policy which has been explicitly modelled is the increase in offshore wind capacity and the planned changes to electricity generation mix (E0). Package E1 consists of supporting measures that were not explicitly modelled. Table 6-7 and Table 6-8 demonstrate the cumulative impact of all amendments to the phase 2 modelling work, this includes the replacement of 10-year average load factors derived from BEIS' operational data with BEIS' projected load factors and Peterhead coming online in 2027 instead of 2033.

A comparison between the projected emission reduction by 2032 is provided below. As detailed in the Phase 1 report, only offshore wind capacity targets were included in the "Full Assessment" and there are no Electricity sector targets to compare the impact of these amendments in Phase 2 against.

Table 6-8. Emission reduction contributions (in $ktCO_2e$) of Electricity sector policy packages under model scenarios by 2032, with respect to the baseline.

Policy Package	Emissions reductions by 2032 ($ktCO_2e$)					
	Phase 1			Phase 2		
	Central Growth	High Growth	Low Growth	Central Growth	High Growth	Low Growth
E0	-45	-45	-45	-1,462	-1,462	-1,462
E1	0	0	0	0	0	0
Total	**-45**	**-45**	**-45**	**-1,462**	**-1,462**	**-1,462**

6.4 Uncertainties

There is uncertainty regarding projections of electricity generation for power schemes that have received planning permission and projections of electricity generation from the offshore wind policy. The uncertainty comes in three forms for sites that have received planning permission:

- Will the load factor be representative of the proposed sites?;
- Will the constructed schemes achieve the desired capacity set out in planning?;
- Will the proposed schemes be constructed and operational by 2032?; and
- The annual rate of electricity generation is assumed to be linear between 2019 and 2032, in reality the growth will be non-linear and this affects the accuracy of generation estimates for intermediary years.

The uncertainty due to load factors is 4% as the maximum standard deviation is 4% across all renewable technologies. However, this is based on existing and current technologies and technological improvements is expected to increase the load factor (proportion (%) of year that the plant is generating electricity) and uncertainty associated with it. However, the increasing load factor of renewable technologies is likely to reduce usage of the CCS gas power station and therefore reduce GHG emissions. Further to this there is the uncertainty of whether the renewable operations awarded planning permissions will become operational. However, this has not been quantified in this project.

For renewable generation from the offshore wind policy, in addition to the above, there is also uncertainty around the capacity of sites that have already received planning permission that will be discounted from the 8 to 11 GW target. Taking a conservative approach, the maximum reduction this could have on the additional capacity (GW) constructed by this policy, energy generation could be reducing it by approx. 40%. As 3.76 GW of offshore wind farms have received planning permission and in 2019 are still waiting to become operational.

Built environment electricity demand:

As explained in Section 55, there are a variety of policies and targets in place that would see fossil fuel heating being phased out in favour of zero direct emission heating systems (ZDEH). However, at present, the precise mix of technologies is not known. Furthermore, some targets for buildings (e.g. reducing the emissions intensity of non-domestic buildings) could be achieved through demand reduction measures and/or switching to ZDEH, but again the regulatory approach has not yet been determined. This increases the level of uncertainty when it comes to electricity use in the built environment, both in terms of annual and peak demand. This could potentially have a significant impact on the Electricity sector's emissions because, if demands are significantly higher or lower, a different mix of technologies – potentially with a higher proportion of non-renewables – might be necessary to meet these demands. This, in turn, could impact on emissions from the Electricity sector.. Whilst there are substantial renewable generation projects in the planning pipeline that could fully meet the increasing demands from ZDEH, the intermittent nature of renewables in-combination with the lack of current capabilities to store excess electricity generation could lead to a greater reliance on CCS at Peterhead.

6.5 Sensitivities

GHG emissions in the Electricity sector are primarily sensitive to the carbon intensity of the Scottish electricity generation plants that are used to meet overall GB electricity demand, which is partially beyond Scotland's control. Scotland can contribute to grid decarbonisation by ramping up renewable installations. However, decisions as to which type of generating plant is dispatched at any given time is based on GB-wide demand and generating plant availability, along with availability of electricity and its price over the interconnectors in either direction. Reducing reliance on the one remaining CCS gas power station will mean that increasingly grid balancing will be met by renewable technologies and reduce GHG emissions associated with this.

7. Industry sector

7.1 Sector Overview

7.1.1 Sector Background

Emissions from Industry represent a large proportion of total Scottish emissions, approximately 24% in 2019 according to the scope of Industry used in this study. These emissions are generated from a variety of activities across a diverse range of subsectors, predominantly refining and manufacturing.[30]

Recent Scottish Government commissioned research from Element Energy estimates that it could be possible for emissions from Scotland's large industrial sites to reduce by 80% or more by 2045, while maintaining output, if deep decarbonisation pathways are followed.[31]

In early 2023, the Scottish Net Zero Roadmap was published, which focuses on ways to decarbonise the industrial cluster along Scotland's east coast. The Roadmap had not been published at the time this analysis was undertaken but it provides useful additional context for net zero policies affecting this sector.[32]

7.1.2 Subsectors Considered

The Industry sector was disaggregated into the following subsectors:

- Cement
- Chemicals
- Food & Beverage
- Glass
- Metals
- Oil & gas extraction
- Paper
- Refineries
- Other (ETS installations)
- Other (non-ETS installations)

[30] Scottish Government, *'Securing a green recovery on a path to net zero: climate change plan 2018–2032 – update'* (2020). Available at: https://www.gov.scot/publications/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/documents/

[31] Scottish Government, *'Deep decarbonisation pathways for Scottish industries'* (2020). Available at: https://www.gov.scot/publications/deep-decarbonisation-pathways-scottish-industries/

[32] NECCUS, *'Scottish Net Zero Roadmap'* (2023). Available at: https://snzr.co.uk/

7.1.3 Data Sources

Table 7-1: A summary of the main data sources used in the assessment of the Industry sector.

Purpose	Data used	Comment
GHG inventory and energy consumption for Scotland	UK National Atmospheric Emissions Inventory (UK NAEI) 2019	GHG inventory and energy consumption for Scotland needed to estimate impacts of policies on emissions and energy use.
UK ETS trajectory	Developing the UK Emissions Trading Scheme (UK ETS) A joint consultation of the UK Government, the Scottish Government, the Welsh Government and the Department of Agriculture, Environment and Rural Affairs for Northern Ireland[33], 2022	Trajectory of cap under UK ETS
Industry subsector emission reductions	Deep Decarbonisation Pathways for Scottish Industries A study for the Scottish Government[30], 2020	Abatement contributions to each subsector's decarbonisation potential by 2045
Industry indicators	Climate Change Plan Monitoring Reports May 2021[34]	Industrial energy productivity and industrial emissions intensity in Scotland

7.1.4 Underlying Drivers of Energy & Emissions

The following driver of energy and emissions was considered:

[33] UK Government, the Scottish Government, the Welsh Government and the Department of Agriculture, Environment and Rural Affairs for Northern Ireland, *'Developing the UK Emissions Trading Scheme (UK ETS)'* (2022). Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067125/developing-the-uk-ets-english.pdf

[34] Scottish Government, *'Climate Change Plan: Monitoring Reports – 2021 Compendium'* (2021). Available at: https://www.gov.scot/publications/climate-change-plan-monitoring-reports-2021-compendium/pages/5/

- **Gross value added (GVA):** Current GVA figures for each subsector were estimated using data from a 2021 ClimateXChange project that examined the impacts of emissions trading systems (average 2017-18 proxy used).[35] A projected annual growth of 0.7% was assumed for all subsectors, based on the 10-year average change in GVA as per ONS data.

7.2 Policy Measures and Outcomes Modelled

7.2.1 Phase 1 – Policy Measures

The primary policy for reducing GHG emissions from emissions intensive industries is the **UK ETS.** The key metric is the annual rate of reduction of the cap, which was applied to the portion of emissions from Industry that is included under the ETS.

Following our initial research, it was determined that insufficient data relating to the impacts of policies was available to fully assess the impacts of many of the policies/funds/proposals, namely the Scottish Industrial Decarbonisation Partnership and Making Scotland's Future programme. It was also decided that these policies are essentially enablers to support reductions being made within the ETS, and so including them would not change our analysis as those reductions would occur within the ETS cap anyway. Although data on the expected impacts of the Acorn CCS project was available, it was agreed that this would fall within ETS, so to avoid double counting this policy was not considered separately. The Acorn CCS project is also an example of the risks of delivering emissions reductions with policies that are outside the control of Scottish Government and require action at the UK government level.

It was agreed with Scottish Government that:

- For ETS sub-sectors (e.g. Chemicals, Glass etc), the UK ETS is considered as the overarching policy measure, with other policies being considered to be supporting measures, essentially enablers to support ETS objectives, so we did not model their impacts separately.
- For the "Other (non-ETS)" sub-sector, we considered the impacts of the Scottish Industrial Energy Transformation Fund, for which some indicative information was provided by Scottish Government

The following were considered to be policy measures:

- **UK ETS:** Emissions reductions in industry are expected to take place in line with the UK ETS trajectory. The trajectory was based on proposed changes to align the UK ETS cap and trajectory with the UK's net zero target.[36] This includes different

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[35] ClimateXChange, *'Understanding the impacts of emission trading systems and carbon border adjustment mechanisms on Scottish business'* (2022). Available at: https://www.climatexchange.org.uk/research/projects/understanding-the-impacts-of-emission-trading-systems-and-carbon-border-adjustment-mechanisms-on-scottish-business/

[36] UK Government, the Scottish Government, the Welsh Government and the Department of Agriculture, Environment and Rural Affairs for Northern Ireland, *'Developing the UK Emissions Trading Scheme (UK*

trajectories for Phase 1 & 2 (2020- 2030) and Phase 3+ (2030 onwards) to reflect the different rates of reduction of the cap proposed for these periods. Although the cap is not expected to reduce linearly in Phases 1 and 2, Figure 4a in the analytical annex of the UK ETS consultation on carbon pricing[37] suggests that, in practice, emission reductions will be approximately linear up to 2030, as a result of the distribution of unallocated allowances. We therefore decided that disaggregating emissions reductions from the UK ETS into more steps would not provide significant additional value to this study at this stage. Given the nature of the emissions trading system, if reductions occur more quickly in one subsector, this allows for a slower rate of reduction in another sector through trading of allowances, and thus the net effect is alignment with the cap.

- The **Scottish Industrial Energy Transformation Fund (SIETF)** was also considered for the "Other (non-ETS)" sub-sector, based on an estimate by Scottish Government that it is expected to account for approximately 1% reduction of current total Industry emissions.

While not technically policies, three key methods of industrial decarbonisation**—**CCUS, fuel switching and improvements in energy efficiency—were treated as policy measures in the context of the model. The level of decarbonisation attributed to each of these technological solutions for each sub-sector was estimated based on existing literature. An indication of the impacts of these three drivers is provided below:

- **CCUS** is expected to be the main driver of decarbonisation in the oil and gas, chemicals, and cement sectors, delivering about 60% of the emissions abatement within these sectors. Note, although bioenergy and CCS ('BECCS') is expected to deliver negative emissions within the cement industry this was not considered here as it falls within the scope of the 'negative emissions technologies' sector.

- **Fuel switching** is expected to account for about two thirds of the emission reductions in other sub-sectors and 41% of the overall abatement. It should be noted that CCUS could also be considered instead of fuel switching, especially for large emission sources or those located in a CCS cluster, since it would deliver comparable emission reductions.

  The following assumptions were used to estimate fuel switching in certain subsectors:

  - Cement: A projected fuel mix of 70% of the thermal input from biomass, 20% from hydrogen and 10% from plasma (electrification), as modelled in a recent

ETS)' (2022). Available at: https://www.gov.uk/government/consultations/developing-the-uk-emissions-trading-scheme-uk-ets

[37] UK Government, the Scottish Government, the Welsh Government and the Department of Agriculture, Environment and Rural Affairs for Northern Ireland, *'Analytical Annex to Developing the UK Emissions Trading Scheme (UK ETS)'* (2022). Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067127/developing-uk-ets-consultation-analytical-annex.pdf

Feasibility Study for the Department for Business Energy and Industrial Strategy[38]

- Chemicals: Fuel switching again assumed to take place from fossil fuels to biomass, hydrogen and electrification. 55% blue and 45% green hydrogen assumed in line with 'Hydrogen pathway' to 2045[34]
- Food & drink: Fuel switching assumed to be to biomass[39] - in practice there are other options, e.g. some potential for electrification, but these were not modelled, to simplify the analysis
- Metals: It is assumed that in the future there will be an equal mix of biomass, electricity and hydrogen, as all three are considered potential options[40]
- Paper: It is assumed that fossil fuels are completely replaced by grid electricity in line with high emission reduction scenario in a recent study[41]
- Refineries: It is assumed that the ratio of blue:green hydrogen is 1:1, in line with the expectation that both will be utilised at the Grangemouth refinery[42]

- Incremental improvements in **energy efficiency** offer a moderate overall contribution (11% on average) but play a more important role in certain subsectors (e.g. food and drink).

7.2.2 Phase 2 – Outcomes

During Phase 2 of the project, Scottish Government requested to reflect in the modelling the fact that UK ETS cap had not yet come into effect. It was therefore agreed that 2024 should be used as the beginning of the UK ETS, rather than 2020 as had been used in Phase 1.

The only other change was to the GVA, changing projected annual GVA growth in industrial subsectors to 0.7%, in line with the 10-year average for Scotland[43], for all

[38] Mineral Products Association, *'Options for switching UK cement production sites to near zero CO_2 emission fuel: Technical and financial feasibility – Summary Report'* (2019). Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/866365/Phase_2_-_MPA_-_Cement_Production_Fuel_Switching.pdf

[39] According to a report by Element Energy on behalf of ClimateXChange, "Fuel switching to bioenergy is particularly relevant to industries that generate organic process residues, like the food and drink, paper and pulp, and wood processing sectors." Element Energy, *'Promoting project progression: Creating a pipeline for industrial decarbonisation in Scotland'* (2020). Available at: http://www.element-energy.co.uk/wordpress/wp-content/uploads/2020/12/industrial-decarbonisation-pipeline-report-final-december-2020.pdf

[40] Element Energy, *'Promoting project progression: Creating a pipeline for industrial decarbonisation in Scotland'* (2020). Available at: http://www.element-energy.co.uk/wordpress/wp-content/uploads/2020/12/industrial-decarbonisation-pipeline-report-final-december-2020.pdf

[41] Rahnama Mobarakeh, M.; Santos Silva, M.; Kienberger, T. Pulp and Paper Industry, *'Decarbonisation Technology Assessment to Reach CO_2 Neutral Emissions—An Austrian Case Study'*. Energies 2021, 14, 1161. Available at: https://doi.org/10.3390/en14041161

[42] Reuters, *'INEOS to switch Grangemouth to hydrogen in $1.4 bln pursuit of net zero'* (2021). Available at: https://www.reuters.com/business/energy/ineos-switch-grangemouth-hydrogen-14-bln-pursuit-net-zero-2021-09-21/

[43] ONS Data on Regional GVA Chain Index (2017=100), Deflated

subsectors rather than the 0.8% used during Phase 1 of the project. The revised growth figure was retroactively applied to the Phase 1 results.

Table 7-2, below, shows the additional outcomes and targets that were to be considered during Phase 2.

Table 7-2. Additional impacts modelled in the Industry sector

Outcome	Target	Additional impacts modelled
Scotland's Industrial sector will be on a managed pathway to decarbonisation, whilst remaining highly competitive and on a sustainable growth trajectory.	No specific target- Scottish industry emissions will align with UK ETS pathway	None. ETS pathway already followed
Technologies critical to further industrial emissions reduction (such as carbon capture and storage and production and injection of hydrogen into the gas grid) are operating at commercial scale by 2030	% of Scottish gas demand accounted for by biomethane and hydrogen blended into the gas network – No target	None required

It was agreed that, due to the nature of these targets, no further modelling was required, besides the updates outlined above in section 7.3.1. These updates were applied to both Phases, for consistency.

7.2.3 Summary of Policy Packages

The table below indicates which policies were found to have the biggest potential impact within each package, which policies overlap with (or reinforce) each other, and which policies act as supporting measures.[44]

The primary policy for reducing GHG emissions from emissions intensive industries is the UK ETS, with other policies essentially enablers to support reductions being made within the ETS. For sectors that are not subject to the ETS, the key policy for reducing emissions is the Scottish Industrial Energy Transformation Fund.

[44] The following descriptions have been used:

- **Key policies** are those that are expected to have the largest direct, tangible impacts on emissions, relative to others within each package.
- **Supporting measures** are those that will not have a direct, quantifiable impact on emissions, but may create an enabling environment or facilitate development of further policies/actions that will have a direct impact.
- **Overlapping/reinforcing measures** are those that interact with (and often contribute to the same activity impacts as) other policies - modelling these policies separately without consideration of interactions with other policies would incur double counting of emissions reductions.

Table 7-3. Policy packages for the Industry sector – I1 policies 1-5

Policy	Categorisation
Policy 1: Emissions Trading Scheme (ETS): following EU Exit we will work with UK Government and other devolved administrations on maintaining carbon pricing that is at least as ambitious as the EU ETS. The Scottish Government's preference is to establish a UK ETS will have an interim cap 5% tighter than the EU ETS and will be reviewed for consistency with Net Zero in 2021.	Key policy
Policy 2: Deliver an Energy Transition Fund (ETF) to provide support for a sustainable, secure and inclusive energy transition in the North-East.	Supporting measure
Policy 4: Making Scotland's Future: multi-faceted programme will boost manufacturing productivity, innovation, and competitiveness, supporting manufacturing businesses to make the transition to net zero and realise the opportunities of a low carbon economy.	Supporting measure
Policy 5: Low Carbon Manufacturing Challenge Fund: to support innovation in low carbon technology, processes and infrastructure. Will be based on successful delivery of ERDF funded Advancing Manufacturing Challenge Fund.	Supporting measure

Table 7-4b. Policy packages for the Industry sector – I1 proposals

Policy	Categorisation
Proposal 1: Scottish Industrial Decarbonisation Partnership (SIDP): Scottish Government-convened cross-sector energy-intensive industrial (EII) stakeholder forum with representatives from manufacturing sites. Initial objectives: bring together other initiatives; build a shared narrative between government/industry on decarbonisation; and disseminate best-practice.	Supporting measure
Proposal 2: Deliver a Net Zero Transition Managers Programme to embed Managers in organisations tasked with identifying, quantifying and recommending decarbonisation opportunities for the business.	Supporting measure
Proposal 3: Establish a Grangemouth Future Industry Board (GFIB) – forum to coordinate public sector initiatives on growing economic activity at the Grangemouth industrial cluster, whilst supporting its transition to our low-carbon future.	Supporting measure
Proposal 4: Develop policy on providing market-benefit for Scottish industries that invest to decarbonise production.	Supporting measure
Proposal 5: Green Jobs Fund, to help businesses create new, green jobs, working with enterprise agencies to fund businesses that provide sustainable or low carbon products and services to help them develop, grow and create jobs. Further funding will help to ensure that businesses and supply chains across Scotland can capitalise on our investment in low carbon infrastructure such as the decarbonisation of heating and green transport.	Supporting measure
Proposal 6: Seizing the economic opportunity, we will work across government, enterprise agencies and the innovation system to identify strengths that can be built on as part of the decarbonisation journey, for example on The Clyde Mission and continued support for the Michelin Scotland Innovation Parc (MSIP).	Supporting measure

Table 7-5c. Policy packages for the Industry sector – I1 CCS and Hydrogen Policies and proposals

Policy	Categorisation
Policy 1: ACORN CCS Project: support the delivery of the CCS and Hydrogen capability at St. Fergus Gas Processing complex by 2025.	Supporting measure
Policy 2: Establish and deliver a Carbon Capture and Utilisation (CCU) Challenge Fund.	Supporting measure
Proposal 1: Emerging Energy Technologies Fund – to support the development of Hydrogen, CCUS and Negative emissions technologies.	Supporting measure
Proposal 2: Carbon Capture Utilisation and Storage (CCUS): work closely with the UK Government to get commercial, policy and regulatory frameworks required to support CCUS at scale in the UK."	Supporting measure
Proposal 3: Forums for CCUS and Blue (low-carbon) Hydrogen: to bring together industry, academics and membership organisations to promote and attract investment in CCUS and Blue Hydrogen.	Supporting measure
Proposal 4: Evidence for CCUS and Blue Hydrogen: building the evidence base on impact of technology, regulatory and market barriers.	Supporting measure
Proposal 5: Strategic development of Scotland's hydrogen economy – This is a cross-portfolio proposal that will impact on the delivery of multiple outcomes.	Supporting measure
Proposal 6: Hydrogen Demonstration: to replicate and scale-up demonstration projects and the evidence base for hydrogen based technologies.	Supporting measure

Table 7-6d. Policy packages for the Industry sector – I2

Policy Package	Policy	Categorisation
I2 Scottish Industrial Energy Transformation Fund	Policy 3: Establish and deliver a Scottish Industrial Energy Transformation Fund (SIETF) – to support the decarbonisation of industrial manufacturing through a green economic recovery	Key policy

7.2.4 Variation across scenarios

The baseline scenario represents a business-as-usual case which considers GVA as the main driver of emissions while emissions reductions in the central scenario aligns with the trajectory of the UK ETS. The high and low growth scenarios represent scenarios in which emissions reductions occur more slowly and more rapidly than the rest of the UK respectively. The high growth scenario is included on the basis that Scotland missed out on the first round of UK CCS funding which could mean that the rest of the UK declines faster than the UK ETS cap meaning emissions from Scottish industry reduce more slowly.

In the high hydrogen scenario, the Industry sector follows the "Hydrogen" emission trajectory set out in the in "Deep Decarbonisation Pathways for Scottish Industries" report (December 2020). In the low hydrogen scenario, it follows the "Electrification" emission trajectory set out in the same report.[45]

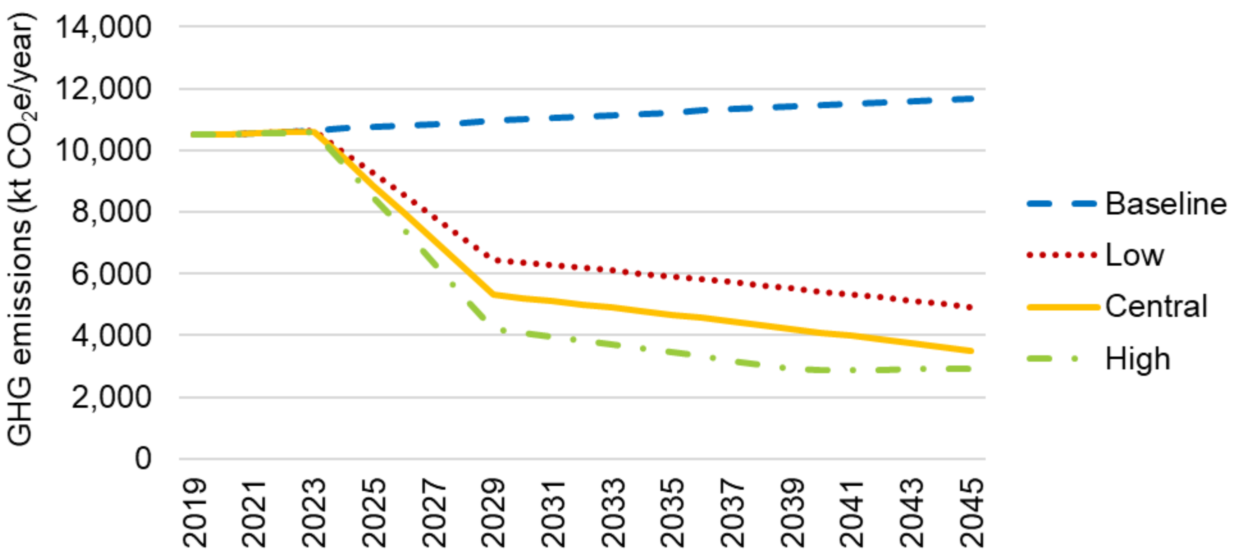
7.3 Emissions Projections

7.3.1 Phase 1 results

Compared to the baseline scenario, in which emissions gradually increase, overall Industry emissions are expected to reduce in line with the UK ETS cap in the projected scenarios. This means emissions are projected to reduce more rapidly initially in line with the steeper decline Phase 1 & 2 of the UK ETS, subject to uncertainties and sensitivities (see Sections 7.6 and 7.7), before a more gradual reduction after 2030. It should be noted that emissions do not reach zero. This is due to residual emissions from non-ETS installation and the fact that BECCS, which is expected to achieve significant emissions reductions in the cement sector, is considered within the Negative Emissions Technologies sector rather than Industry.

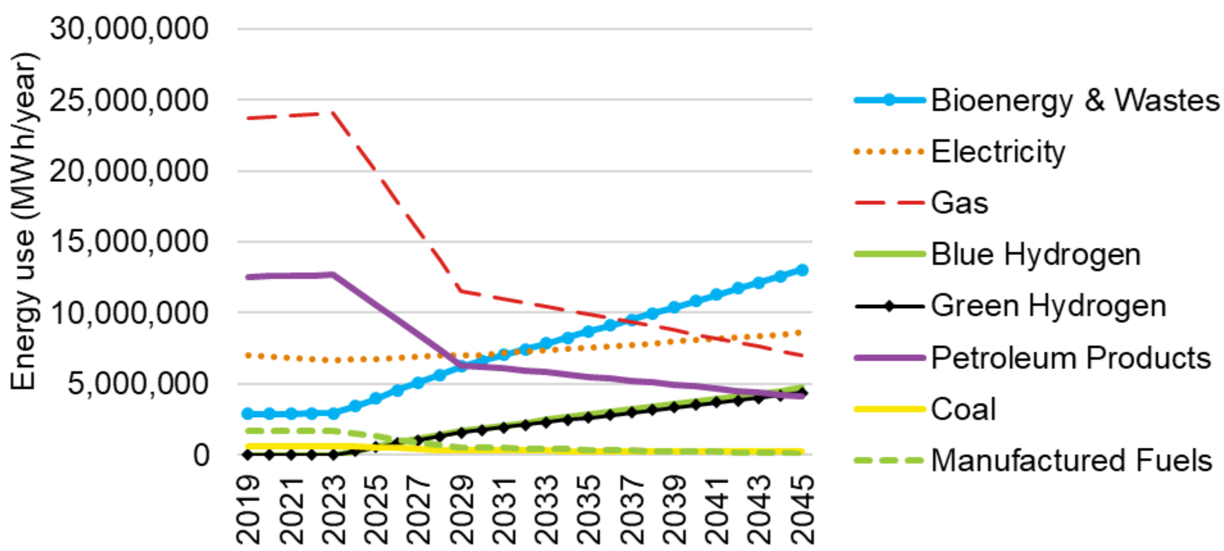
[45] Scottish Government, *'Deep decarbonisation pathways for Scottish industries'* (2020). Available at: https://www.gov.scot/publications/deep-decarbonisation-pathways-scottish-industries/

Figure 7-1. Phase 1 emissions projections under all modelled scenarios for Industry



Projected changes in energy use reflect the fuel switching that is expected to take place within industry subsectors, as outlined in the 'Policy measures' section. Increased use of bioenergy & waste, blue and green hydrogen and renewable electricity is expected within Industry.

Figure 7-2. Projected changes in energy use in the central scenario under Phase 1



7.3.2 Phase 2 results

The additional modelling work resulted in slight changes in the modelling outputs, as shown in Figure 7-3 and Figure 7-4 below.

Figure 7-3. Phase 2 emissions projections under all modelled scenarios for Industry

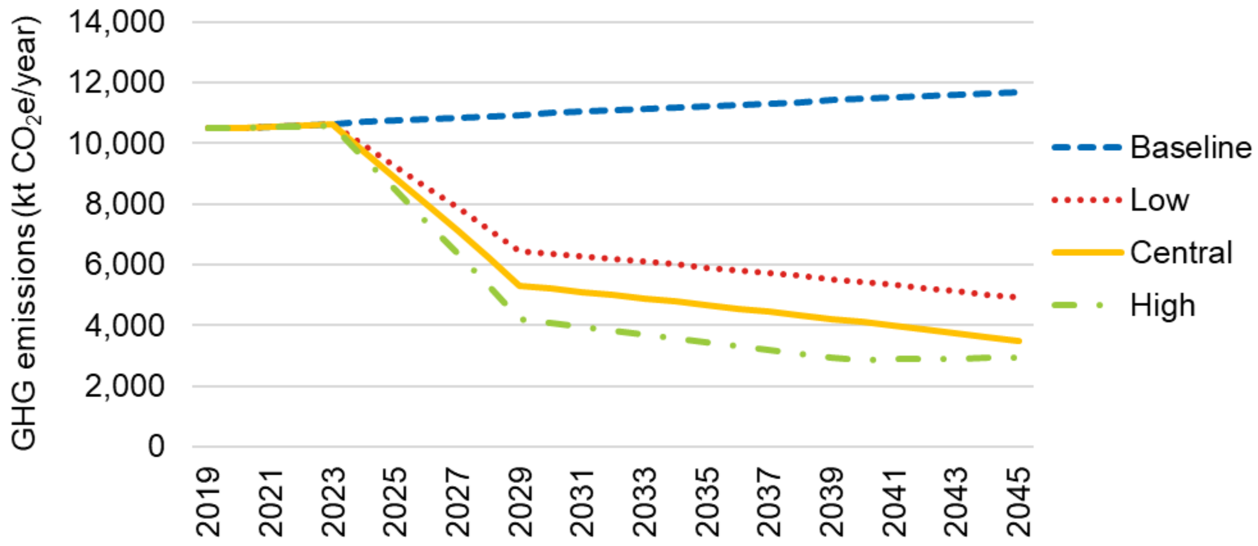
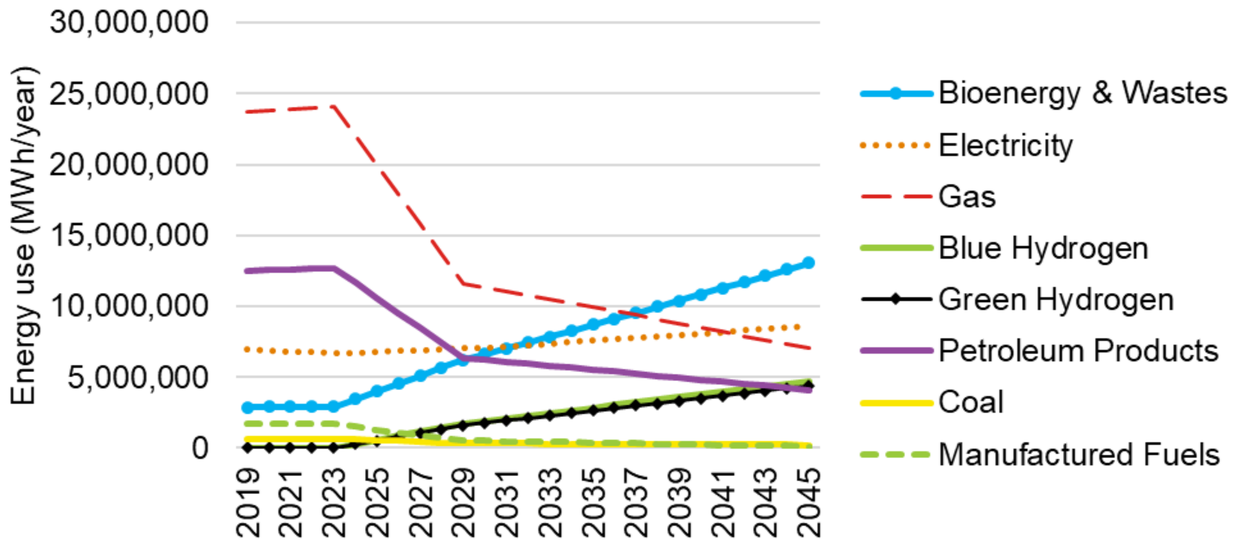


Figure 7-4. Projected changes in energy use in the central scenario under Phase 2



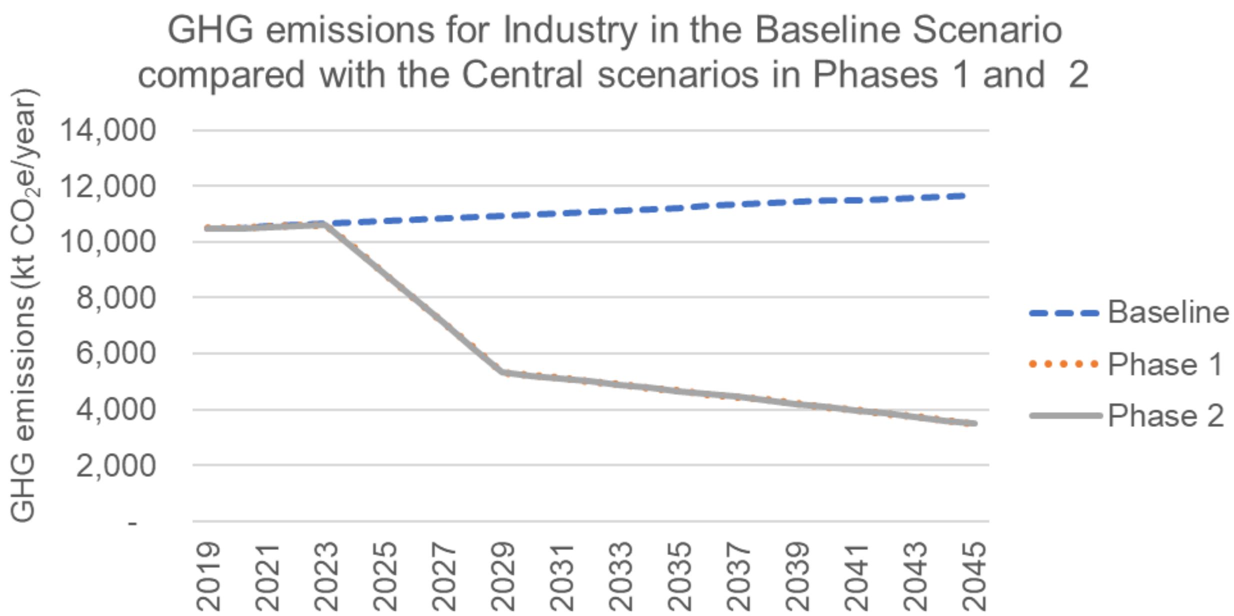
7.3.3 Comparison of Phases 1 & 2

Emissions projections from the Industry sector in the baseline scenario and central scenario (for both phases 1 and 2 of the project) are provided below. No changes are observed in the emissions from the sector calculated in the two phases of the project, as updates under Phase 2 were also copied back into Phase 1 results, for consistency.

Table 7-7. Emission projections for the Industry sector under the baseline and under modelled scenarios, for both Phase 1 and Phase 2 (in $ktCO_2e$)

Phase	Scenario	Emissions ($ktCO_2e$)						
		2019	2020	2025	2030	2035	2040	2045
n/a	**Baseline**	**10,491**	**10,496**	**10,748**	**10,994**	**11,231**	**11,461**	**11,683**
1	**Central Growth**	**10,491**	**10,495**	**8,866**	**5,216**	**4,671**	**4,097**	**3,497**
	High Growth	10,491	10,494	8,489	4,081	3,444	2,858	2,937
	Low Growth	10,491	10,495	9,245	6,365	5,908	5,425	4,920
	High Hydrogen	10,491	10,495	8,370	3,704	3,122	2,883	2,964
	Low Hydrogen	10,491	10,495	9,362	6,737	6,226	5,684	5,119
2	**Central Growth**	**10,491**	**10,495**	**8,866**	**5,216**	**4,671**	**4,097**	**3,497**
	High Growth	10,491	10,494	8,489	4,081	3,444	2,858	2,937
	Low Growth	10,491	10,495	9,245	6,365	5,908	5,425	4,920
	High Hydrogen	10,491	10,495	8,370	3,704	3,122	2,883	2,964
	Low Hydrogen	10,491	10,495	9,362	6,737	6,226	5,684	5,119

Figure 7-5: Differences in emissions from the Industry sector between the modelling results from the Baseline scenario, and the Central scenarios in Phases 1 and 2



Note: The results from Phases 1 and 2 are visibly almost indistinguishable from each other because of the small magnitude of differences between them.

7.3.4 Emissions reduction by policy package (2032) – Phase 1 & 2

A breakdown of emissions reduction by policy package— I1 (UK ETS) and I2 (Scottish Industrial Energy Transformation Fund) —by scenario in 2032 is provided below. This again shows the marginal differences between the results of the modelling undertaken during phase 1 and phase 2 of the project.

Table 7-8. Emission reduction contributions (in $ktCO_2e$) of Industry sector policy packages under model scenarios by 2032, with respect to the baseline

Policy Package	Emissions reductions by 2032 ($ktCO_2e$)									
	Phase 1					Phase 2				
	Central Growth	High Growth	Low Growth	High Hydrogen	Low Hydrogen	Central Growth	High Growth	Low Growth	High Hydrogen	Low Hydrogen
I1	-6,013	-7,178	-4,842	-7,551	-4,476	-6,013	-7,178	-4,842	-7,551	-4,476
I2	-55	-66	-44	-55	-55	-78	-93	-62	-78	-78
Total	**-6,069**	**-7,244**	**-4,886**	**-7,606**	**-4,531**	**-6,091**	**-7,271**	**-4,904**	**-7,629**	**-4,554**

7.4 Uncertainties

In 2019, around 68% of emissions in the Industry sector were produced by sub-sectors covered by the ETS. For emission reductions through the ETS, the overall uncertainty of the industrial sector as a whole achieving the modelled level of emissions by 2045 is expected to be relatively low (perhaps <10%) as it is dictated by the ETS cap. However, there is uncertainty in the years up to 2045 as Scottish industry may decarbonise at a different rate compared to the rest of the UK. This possibility is covered in the High and Low growth scenarios (see 'Sensitivities' section below). There is also uncertainty over how each individual subsector will decarbonise over time which could be ~50% in 2030, with the uncertainty of the emissions in 2045 considerably lower. For non-ETS emissions reductions, the uncertainty throughout the studied period is higher (approx. 50%) due to limitations in available data.

Due to the number of assumptions used, we suggest that the energy use projections are merely indicative. For example, there is a high level of uncertainty associated with the technical and economic characteristics of fuel-switching technologies.

7.5 Sensitivities

High and low growth scenarios reflect possible rates of emission reduction under the ETS in comparison to the rest of the UK. Deviations from the central scenario of ±20% up to 2030 and ±10% thereafter are estimated in the high and low growth scenarios. This reflects the expectation that more significant deviation from the rest of the UK is expected in the short term due to differences in funding allocation for decarbonisation projects within industry.

Variations in trajectory are also considered in the high and low hydrogen pathways, based on "Hydrogen" and "Electrification" emission trajectories in the 'Deep Decarbonisation Pathways for Scottish Industries' report, which consider the expected timeline of key deployments, such as the implementation of CCUS.

8. Transport sector

8.1 Sector Overview

8.1.1 Sector Background

Transport was the largest emitting sector in Scotland in 2019, with around 13.95 million tonnes of CO_2e (including international bunkers)[46]. The National Transport Strategy 2, published in 2020, defines climate change as one of the four priorities in the transport sector for the next two decades. The deployment of sustainable and low carbon energy sources in the transport sector is a key focus area with deployment paces tailored to the varying level of technological maturity across transport modes. In addition, travel behaviour and transport demand management measures are also seen as necessary steps towards the net zero pathway by 2045. Transport infrastructure investment will also be planned consistently to limit traffic increases generated by any capacity expansion. A recent study commissioned by Transport Scotland in 2021, Decarbonising the Scottish Transport Sector, assessed several policy scenarios and their capacity to meet Scotland´s emission targets.

The climate change plan update (CCPu) sets the following key commitments by 2032:

- No new petrol and diesel cars and vans.
- Work to decarbonise challenging transport modes, such as HGVs, ferries and aviation will have started.
- Car kilometres will have reduced by 20%.
- Research into biofuels and hydrogen will have stimulated private investment and innovation.
- Almost complete decarbonisation of passenger railways.

8.1.2 Subsectors Considered

The transport sector was disaggregated into the following subsectors:

- Road transport – Cars
- Road transport – Light goods vehicles (LGVs)
- Road transport – Heavy goods vehicles (HGVs)
- Road transport – Buses and coaches
- Road transport – Public transport fleet
- Road transport – Motorcycles
- Rail transport
- Aviation – Domestic
- Aviation – International
- Shipping – Domestic
- Shipping – International

Road transport has been divided into the main vehicle types to acknowledge their different contribution to overall GHG emissions and their different decarbonisation paces. In addition, we distinguished the public sector fleet, which includes all vehicle types, to model

[46] Greenhouse Gas Inventories for England, Scotland, Wales & Northern Ireland: 1990-2019

specific policies within this segment. For aviation and maritime transport, domestic and international transport emissions have been distinguished.

8.1.3 Data Sources

The main data sources used to undertake the assessment of the transport sector are detailed in Table 8-1 below.

Table 8-1a: A summary of the different data sources used in the assessment of the transport sector.

Purpose	Data used	Comment
GHG inventory for Scotland	**UK National Atmospheric Emissions Inventory (UK NAEI)**	GHG inventory for Scotland needed to estimate impacts of policies on emissions.
Energy consumption in Scotland	**UK National Atmospheric Emissions Inventory (UK NAEI)**	Energy consumption by sub-sector in Scotland needed to estimate impacts of policies on energy use.
Travel behaviour	**Scottish Household Survey 2019**	Mode share, average distance by mode
Road transport traffic	**Scottish Transport Statistics 2021 (Chapter 5)**	Traffic (in million veh-km) by sub-sector and by road type
Road transport traffic forecast	**Transport Model for Scotland (TMfS) - Transport Forecast Derivation**	Expected traffic growth by 2045 without further policy action
Road vehicle characteristics	**Scottish Transport Statistics 2021 (Chapter 1 and 13)**	Licenced fleet, new vehicle registrations, ultra-low emission vehicles (ULEV) licenced, ULEV new registrations, average emission factor (in gCO_2/km)
Public sector fleet characteristics	**Transport Scotland Decarbonisation Fleet Research Report 2020**	Number of vehicles by type and share of GHG emissions by vehicle type

Table 8-2b: A summary of the different data sources used in the assessment of the transport sector - continued.

Purpose	Data used	Comment
Rail traffic and network characteristics	**Scottish Transport Statistics 2021 (Chapter 7)**	Passenger activity (in million pax-km) and freight activity (in thousand net tonne-km)
Rail passenger traffic projections	**Transport Scotland - Transport Forecasts 2018**	Forecasted demand growth by 2030 and 2045
Rail freight traffic projections	**Network Rail - Rail freight forecasts: Scenarios for 2033/34 & 2043/44**	Forecasted demand growth
Air transport traffic	**Scottish Transport Statistics 2021 (Chapter 8)**	Aircraft movements for domestic and international aviation
Air transport traffic projections	**UK Jet zero strategy (Scenario 1- Continuation of current trends)**	Expected growth in air transport movements by 2050
Shipping activity	**Scottish Transport Statistics 2021 (Chapter 8)**	Domestic and international freight traffic at major ports (in thousand tonnes)
Shipping activity projections	**UK Port Freight Traffic 2019 Forecasts**	Forecasted growth in freight traffic
Ferries fleet characterisation	**CalMac - Environmental Strategy 2021-2023** **Audit Scotland - Transport Scotland's ferry services**	Number of ferries, total energy consumption and CO_2 emissions

8.1.4 Underlying Drivers of Energy & Emissions

Table 8-3 presents the underlying drivers for each sub-sector, which constitute the baseline scenario to be compared against policy scenarios in the following sections.

Table 8-3a: Drivers and assumptions per sub-sector – Cars and LGVs

Sub-sector	Drivers	Main assumptions
Cars	Traffic (in veh-km)	Projections as per high scenario of latest TMfS traffic projections. This represents the "without policy" scenario.
	Energy efficiency	Fleet-wide energy consumption decreasing by 2% annually as per current and future EU emission standards and considering fleet replacement ratio.
	Uptake of ULEV	Growth rate for ULEV assuming 2018/2019 growth rate remains constant. Average annual mileage per car assumed at 15.000 km. Average energy consumption for ICE cars assumed at 8 MWh. EV energy consumption assumed at 200 Wh/km.
LGVs	Traffic (in veh-km)	Projections as per high scenario of latest TMfS traffic projections. This represents the "without policy" scenario.
	Energy efficiency	Fleet-wide energy consumption decreasing by 2.5% annually as per current and future EU emission standards and considering fleet replacement ratio.
	Uptake of ULEV	Growth rate for ULEV assuming 2018/2019 growth rate remains constant. Average annual mileage per LGV assumed at 26.000 km. Average energy consumption for ICE cars assumed at 20 MWh. EV energy consumption assumed at 230 Wh/km.

Table 8-4b: Drivers and assumptions per sub-sector – other vehicles

Sub-sector	Drivers	Main assumptions
HGVs	Traffic (in veh-km)	Projections as per high scenario of latest TMfS traffic projections. This represents the "without policy" scenario.
	Energy efficiency	Fleet-wide energy consumption decreasing by 1.2% annually as per current and future EU emission standards and considering fleet replacement ratio.
	Uptake of ULEV	Growth rate for ULEV assuming 2018/2019 growth rate remains constant. Average energy consumption for ICE HGV assumed at 167 MWh. Energy consumption for ULEV assumed to be half of that of ICE.
Buses	Demand (in passenger journeys)	Slight decrease in passengers as per Transport Scotland Projections 2018
	Uptake of ULEV	Growth rate for ULEV assuming 2018/2019 growth rate remains constant. Average energy consumption for ICE bus assumed at 129 MWh. Energy consumption for ULEV assumed to be half of that of ICE.
Motorcycles	Traffic (in veh-km)	Projections as per high scenario of latest TMfS traffic projections. This represents the "without policy" scenario.
	Uptake of ULEV	Growth rate for ULEV assuming 2018/2019 growth rate remains constant.
Aviation (domestic and international)	Aircraft movements	1.3% ATM growth as per baseline scenario (current trends) of the UK jet zero strategy 2022
	Energy efficiency	1.5% energy efficiency improvement as per assumptions of the UK jet zero emission strategy (current trends scenario)
Shipping (domestic and international)	Freight demand (in tonnes)	2.8% growth as per UK Port Freight Traffic 2019 Forecasts

8.2 Policy Measures and Outcomes Modelled

8.2.1 Phase 1 – Policy Measures

For the transport sector there were a total of 49 policies which were reviewed and grouped into 8 themes, to allow policies with similar objectives to be assessed together and thus ensure interactions between similar policies/proposals were captured. All 49 policies are captured in the packages, but with many included in a supporting role, rather than a quantifiable role.

Policies under the first theme are related to transport demand management and aim to reduce car use by reducing the need to travel (or reducing travel distances), promoting a shift to more sustainable transport modes and promoting shared journeys. These policies are part of the route map to achieve a 20 per cent reduction in car kilometres by 2030.[47]

Policies under the following themes aim to promote the update of ultra-low emission vehicles (ULEVs) for road vehicles, with different paces, reflecting variations in technology maturity.

Policies to decarbonise the aviation and maritime sector with a focus on domestic operations were also screened. For aviation the focus is on flights in the HIAL region while maritime decarbonisation efforts will focus on ferry services. Low carbon traction options are more limited for these sectors (at least in the short term), which means that they may significantly rely on the use of sustainable drop-in fuels (sustainable aviation fuels (SAF) in the case of aviation).

The roadmap to decarbonise passenger rail services is well developed in the Rail Services Decarbonisation Action Plan in line with the UK-wide Traction Decarbonisation Network Strategy developed by National Rail.

[47] Transport Scotland, *'A route map to achieve a 20 per cent reduction in car kilometres by 2030'* (2022). Available at: https://www.transport.gov.scot/publication/a-route-map-to-achieve-a-20-per-cent-reduction-in-car-kilometres-by-2030/

Table 8-5a: Description of policies and targets by theme

Theme	Quantifiable targets	Relevant policies / strategies / actions
Travel demand management	Overall target: Reduce car-km by 20% by 2030. Related goals: • Increase share of active travel • Increase share of public transport use • Reduce frequency and distance of car journeys • Increase car occupancy levels	• Investment in active travel projects • Investment in bus priority infrastructure • Discounted and free public transport for young, older and disabled people • Support flexible working schemes including remote working • Support innovation in Mobility-as-a-Service schemes
Ultra-low emission cars and vans	Overall target: Phase out new petrol and diesel cars and vans by 2030.	• Low Carbon Transport Loan to support the switch to low carbon vehicles • Investment in the electric vehicle charging network
Ultra-low emission vehicles in public fleets	Overall target: Phase out new petrol and vehicles by 2030. Related targets: • Phase out new petrol and vehicles light commercial vehicles by 2025.	• Procurement practices that encourage electric vehicles • Switched on Fleets programme
Ultra-low emission heavy duty vehicles	Overall target: Phase out new petrol and diesel heavy duty vehicles by 2035.	• Zero Emission heavy duty vehicle programme to support businesses

Table 8-6b: Description of policies and targets by theme – continued

Theme	Quantifiable targets	Relevant policies / strategies / actions
Ultra-low emission buses	Overall target: Majority of new buses are zero-emission by 2024	• Revised green incentive of the Bus Service Operators Grant • Government financial support to decarbonise the bus sector
Low emission aircrafts and Sustainable Aviation Fuel (SAF)	Overall target: Decarbonise intra-Scotland flights by 2040. Related targets: • 10% SAF use by 2030 (UK-wide target)	• Incentivise the use of SAF • Zero emission aviation region in partnership with Highlands and Islands Airports Limited (HIAL)
Low emission ferries	Overall target: 30% of low emission ferries by 2032	• Consider low emission ferries as part of the public sector ferry fleet
Rail network decarbonisation	Overall target: Decarbonise passenger rail services by 2035 Related targets: • Network electrification (or battery/hydrogen infrastructure available) by 2035	• Investment in electrification and complementary alternative traction systems

The result of this grouping was the packaging of the 49 policies into 12 packages. These 12 packages, mapped against the policy outcomes for the transport sector, are presented below.

Table 8-7. Description of policy packages per policy outcome for the transport sector

Outcome	Policy packages
Outcome 1: To address our overreliance on cars, we will reduce car kilometres by 20% by 2030	Package T1: Reducing the need to travel and living well locally Package T2: Switching mode - Promote active travel Package T3: Switching mode - Promote public transport Package T4: Combining trips or sharing journey
Outcome 2: We will phase out the need for new petrol and diesel cars and vans by 2030	Package T5: Promotion of ULEV (cars and vans) Package T6: Promotion of ULEV (cars and vans) in public sector fleets
Outcome 3: To reduce emissions in the freight sector, we will work with the industry to understand the most efficient methods and remove the need for new petrol and diesel heavy vehicles by 2035.	Package T7: Promotion of low emission heavy duty vehicles
Outcome 4: We will work with the newly formed Bus Decarbonisation Taskforce, comprised of leaders from the bus, energy and finance sectors, to ensure that the majority of new buses purchased from 2024 are zero-emission, and to bring this date forward if possible.	Package T8: Promotion of ultra-low or zero emission buses
Outcome 5: We will work to decarbonise scheduled flights within Scotland by 2040.	Package T9: Promotion of low or zero emission aircrafts and SAF
Outcome 6: Proportion of ferries in Scottish Government ownership which are low emission has increased to 30% by 2032.	Package T10: Promotion of low or zero emission ferries
Outcome 7: By 2032 low emission solutions have been widely adopted at Scottish ports.	Package T11: Promotion of alternative fuel infrastructure in ports
Outcome 8: Scotland's passenger rail services will be decarbonised by 2035.	Package T12: Passenger rail decarbonisation

Travel demand management

Transport Scotland forecasts show that traffic numbers are expected to increase during 2022 as COVID-19 restrictions further relax across the country and a return to work and other previously restricted activities occur. Nonetheless, it is expected, and building on the momentum shown during the pandemic, that digital connectivity will continue to enable people to work and connect with others remotely. Given a working from home element is, however, likely to remain in place during 2022, traffic levels are expected to increase to around 95% of those seen pre-pandemic. Traffic is then expected to further increase over the next 2-3 years as the country and economy recover but before interventions to deliver reductions in car traffic really start to make an impact.

Traffic levels are therefore expected to reach those recorded pre-pandemic during the short-term period. Notwithstanding this, the travel demand management measures put in place should show the capability, opportunity and motivation to choose an alternative to the car and support the foundation for achieving the longer-term goal to reduce car kilometres by 20%, by 2030.

Our assessment concluded, however, that policies promoting a mode shift (triggered by investments in active mobility and bus infrastructure/services) could only deliver a small fraction of the targeted car use reduction. The bulk of the reduction will have to be achieved with travel demand measures effectively reducing the need for travel (e.g. increase in homeworking).

It should be noted that travel behaviour is extremely complex, which makes it very difficult to isolate specific factors triggering a behavioural change. Because of this, effects of the travel demand policies were assessed in an aggregate manner based on scenarios agreed with the Scottish Government technical leads. The following scenarios were considered:

Table 8-8. Modelling assumptions of travel management policies (Phase 1)

Scenario	Outcome	Rationale
Existing travel demand policies	Existing measures are effective in achieving some car use reduction. This has been estimated at 10% reduction in car-km by 2030 in the central scenario. The low and high growth scenarios consider reductions of 5% and 15%, respectively.	Scenario with strong focus on promoting alternative modes and initial measures to reduce travel demand. There is a weak causal relationship between specific policy actions in the area of active travel and public transport and reduced car use, which limits the potential for these policies to effectively deliver car traffic reductions. This is because cross-elasticity of demand from car users to active travel and public transport is low. There is evidence that any increase in active mobility tends to be mostly replacing public transport journeys. It is also important to note that active mobility has a very limited potential to reduce car-km, since only the shortest journeys could be replaced. In addition, reduced car use leading to less congestion could actually have a rebound effect by increasing the capacity of the road network for latent car demand. The effect of economic growth in driving traffic activity is captured by considering lower reduction in traffic with high economic growth, while a low growth scenario would drive a higher reduction in traffic.
Full ambition scenario	Scenario with full policy ambition achieves the 20% car-km reduction target by 2030 by effectively reducing the overall demand for travel	Scenario with full ambition policies in the area of travel demand management, including promotion of homeworking and 20-minute neighbourhood concepts. Reduction in traffic levels is only expected to occur post-2025. With further enhancements to digital connectivity, the need to travel is expected to be reduced through flexible and local working. In addition, broader measures coming forward to support the need to travel less, rather than just reduce the need to travel to work, and with additional demand management measures will see a decline in trips towards the 20% target increasingly taking hold as we approach the 2030 deadline.

Uptake of ULEV for road vehicles

For policies promoting an uptake of ULEV for road transport, we considered that phase-out targets and UK- In line with the Scottish Transport Statistics, ULEVs are defined as vehicles that are reported to emit less than 75g of CO_2 from the tailpipe for every kilometre travelled. In practice, the term typically refers to battery electric, plug-in hybrid electric and fuel cell electric vehicles.

wide bans for new diesel and petrol vehicles will effectively induce a transition to ULEV, with a progressive increase in ULEV sales from 2019 to the phase-out year. This uptake in ULEV will also be supported by policies in place to offer financial and technical support to ULEV users.

In general, we assumed that both the fleet size and the current fleet replacement rate per sub-sector would remain constant throughout the evaluated period.

The main assumption regarding ULEV uptake for the different sub-sectors are described below in Table 8-9. The uptake assumptions largely follow the forecasts elaborated by the Scottish Government.

Table 8-9. ULEV uptake assumptions (Phase 1)

Sub-sector	ULEV sales in 2025 (%)	ULEV sales in 2030 (%)	ULEV by 2040 (% of the fleet)
Cars	26	100	100
LGV	19	100	100
HGV	0	33	85
Buses	100	100	100
Motorcycle	26	100	100
Public sector vehicles	50	100	100

The low growth and high growth scenarios are assumed to decrease and increase, respectively, the number of ULEV in the market. The main driver in this case would be the effect that economic growth may have on the number of vehicles being sold each year.

In the model we have assumed two different phases for the uptake of ULEVs: one from 2020-2030 and another from 2030-2040. This captures the fact that the uptake is expected to be higher from 2030, particularly for vehicle types that are more difficult to decarbonise (e.g. HGVs). Phase 2 modelling acknowledges that the uptake of ULEVs is likely to be less linear than this, by introducing additional 5-year time step between 2020-2025 and 2025-2030. This means that in some years the Phase 1 modelling results estimate a greater emissions reduction potential from policies to promote ULEV uptake than under Phase 2 modelling with full policy ambition.

<u>Decarbonisation of aviation, shipping and railways</u>

Low carbon fuel technologies for aviation and shipping are still at the early stages, which means that the policy landscape is also less well developed. For aviation, we have considered the UK jet zero strategy as the main driver for GHG emission reductions in domestic air transport operations. For shipping, our assessment focused on the targeted decarbonisation of the Scottish ferry fleet.

In rail transport, electrification is expected to be the main driver of decarbonisation. We assumed that the network will be fully electrified (or hydrogen and battery supply infrastructure will be in place) by 2035 in line with the current commitments in Rail Services Decarbonisation Action Plan.

Our assessment build on the following assumptions:

Table 8-10. Modelling assumptions for aviation, shipping and railways (Phase 1)

Sub-sector	Indicators	Assumptions
Aviation	SAF share (%)	10% SAF share by 2030
Shipping	Low emission ferries	30% of ferries (13 in total) will be low emission. Average energy consumption per ferry per year estimated at 14 MWh, as per emissions reported by CalMac in environmental report and total fleet. Energy savings from hybrid ferries estimated at 20% as reported by Rehmatulla (2020)
Railways	Km of network electrification	100% of km electrified (or available for battery or hydrogen traction) by 2035

8.2.2 Phase 2 – Outcomes

A workshop was held to discuss options for modelling additional targets as part of Phase 2 of the Provision of Emissions Projections project. Agreements on modelling assumptions for each policy outcome are summarised in the table below. The workshop was also used to validate modelling assumptions for policy measures in Phase 1.

Following up on the workshop, Transport Scotland shared further data for Phase 2 modelling, notably emissions from air transport within Scotland and recent work on HGV decarbonisation strategy.

As a result of the workshop, the following modelling assumptions per policy outcome were included in the additional modelling under Phase 2.

Table 8-11a. Modelling assumptions per policy outcome (Phase 2) – outcomes 1-4

Policy outcome	Quantifiable targets	Modelling assumptions
Outcome 1: To address our overreliance on cars, we will reduce car kilometres by 20% by 2030	20% reduction in car kms from the 2019 baseline by 2030	20% reduction in car-km by 2030 on 2019 levels in the central scenario. This differs from modelling assumption under Phase 1, which considered partial achievement of the policy outcome with a 10% reduction in car-km by 2030 in the central scenario.
Outcome 2: We will phase out the need for new petrol and diesel cars and vans by 2030	100% new car registrations are ULEV by 2030 100% new van registrations are ULEV by 2030	Targeted values do not differ from those of the Phase 1. However, an additional time step was added to the model. The model now considers the following steps: 2020-2025, 2025-2030, 2030-2040
Outcome 3: To reduce emissions in the freight sector, we will work with the industry to understand the most efficient methods and remove the need for new petrol and diesel heavy vehicles by 2035.	100% of new HGV registrations are ULEV in 2035	Targeted values do not differ from those of the Phase 1. However, an additional time step was added to the model. The model now considers the following steps: 2020-2025, 2025-2030, 2030-2040
Outcome 4: We will work with the newly formed Bus Decarbonisation Taskforce, comprised of leaders from the bus, energy and finance sectors, to ensure that the majority of new buses purchased from 2024 are zero-emission, and to bring this date forward if possible.	More than half of new buses are ULEV by 2024	Targeted values and modelling assumptions do not differ from those of the Phase 1.

Table 8-12b. Modelling assumptions per policy outcome (Phase 2) – outcomes 5-8

Policy outcome	Quantifiable targets	Modelling assumptions
Outcome 5: We will work to decarbonise scheduled flights within Scotland by 2040.	Net emissions from domestic flights in Scotland are zero by 2040	Besides assumption on SAF uptake by 2030 (included in Phase I), the model also assumes full decarbonisation of domestic flights within Scotland by 2040, which represent 7% of emissions from domestic aviation (i.e. to/from UK destinations)
Outcome 6: Proportion of ferries in Scottish Government ownership which are low emission has increased to 30% by 2032.	30% of Ferries in Scottish Government ownership are low emission by 2032.	Targeted values and modelling assumptions do not differ from those of the Phase 1
Outcome 7: By 2032 low emission solutions have been widely adopted at Scottish ports.	By 2032 low emissions solutions have been widely adopted at Scottish ports	Outcome is not likely to lead to GHG emission reduction by itself. Targeted values and modelling assumptions do not differ from those of the Phase 1
Outcome 8: Scotland's passenger rail services will be decarbonised by 2035.	Scotland's passenger rail services will be decarbonised by 2035	Targeted values and modelling assumptions do not differ from those of the Phase 1

8.2.3 Summary of Policy Packages

The table below indicates which policies were found to have the biggest potential impact within each package, which policies overlap with (or reinforce) each other, and which policies act as supporting measures.[48]

[48] The following descriptions have been used:

- **Key policies** are those that are expected to have the largest direct, tangible impacts on emissions, relative to others within each package.
- **Supporting measures** are those that will not have a direct, quantifiable impact on emissions, but may create an enabling environment or facilitate development of further policies/actions that will have a direct impact.
- **Overlapping/reinforcing measures** are those that interact with (and often contribute to the same activity impacts as) other policies - modelling these policies separately without consideration of interactions with other policies would incur double counting of emissions reductions.

Within the Transport sector, many policies interact with each other, as there may be multiple initiatives (including infrastructure investment) aimed at achieving the same goal. In broad terms, the policies that are likely to deliver the biggest reductions in emissions in this sector will be those that either reduce demand for private transport, or promote a phase-out of fossil fuel road vehicles, ferries and aircraft.

Table 8-13a. Policy packages for the Transport sector – T1

Policy Package	Policy	Categorisation
T1 Reducing the need to travel and living well locally	Policy 1: If the health pandemic has moved to a phase to allow more certainty on future transport trends and people's behaviours – and work and lifestyle choices future forecasting – we will publish a route-map to meet the 20% reduction by 2030 in 2021.	Supporting measure
	Policy 2: Commit to exploring options around remote working, in connection with our work on 20-minute neighbourhoods and work local programme.	Overlapping/reinforcing measure
	Policy 3: COVID-19 has impacted on how we work. We launched a Work Local Challenge to drive innovation in work place choices and remote working to support flexible working and our net zero objectives.	Overlapping/reinforcing measure
	Policy 4: We will work with the UK Government on options to review fuel duty proposals, in the context of the need to reduce demand for unsustainable travel and the potential for revenue generation.	Overlapping/reinforcing measure
	Policy 5: We will work with local authorities to continue to ensure that their parking and local transport strategies have proper appreciation of climate change, as well as the impact on all road users, including public transport operators, disabled motorists, cyclists and pedestrians.	Overlapping/reinforcing measure
	Policy 6: To support the monitoring requirement for the National Transport Strategy set out in the Transport (Scotland) Act 2019, and to further our understanding of how and why people travel, we will develop a data strategy and invest in data.	Supporting measure

Table 8-14b. Policy packages for the Transport sector – T2

Policy Package	Policy	Categorisation
T2 Switching mode - Promote active travel	Policy 7: Continue to support the Smarter Choices, Smarter Places (SCSP) programme to encourage behaviour change. Continue to support the provision of child and adult cycle training, and safety programmes including driver cycling awareness training through Bikeability.	Supporting measure
	Policy 8: Support transformational active travel projects with a £500 million investment, over five years, for active travel infrastructure, access to bikes and behaviour change schemes. Enabling the delivery of high quality, safe walking, wheeling and cycling infrastructure alongside behaviour change, education and advocacy to encourage more people to choose active and sustainable travel. Support the use of E-bikes and adapted bikes through interest free loans, grants and trials.	Key policy
	Policy 9: We have re-purposed almost £39 million of active travel funding for the Spaces for People; this is enabling local authorities to put in place the temporary measures such as pop-up cycle lanes and widening walkways that are needed to allow people to physically distance during transition out of the COVID-19 lockdown.	Overlapping/reinforcing measure
	Policy 10: Support increased access to bikes for all including the provision of public bike and e-bike share.	Overlapping/reinforcing measure

Table 8-15c. Policy packages for the Transport sector – T3

Policy Package	Policy	Categorisation
T3 Switching mode - Promote public transport	Policy 14: We will bring forward a step change in investment with over £500 million to improve bus priority infrastructure to tackle the impacts of congestion on bus services and raise bus usage. We will launch the Bus Partnership Fund in the coming months to support local authorities' ambitions around tackling congestion.	Key policy
	Policy 15: We remain committed to delivering a national concessionary travel scheme for free bus travel for under 19s, and have begun the necessary preparations including planning, research, legal review and due diligence.	Overlapping/reinforcing measure
	Policy 16: We are also carrying out a review of discounts available on public transport to those under the age of 26 – due for completion end of December 2020 (with consultation planned on young people's views on the impacts of COVID 19 and post lockdown measures on public transport usage and behaviour).	Overlapping/reinforcing measure

Table 8-16d. Policy packages for the Transport sector – T4

Policy Package	Policy	Categorisation
T4 Combining trips or sharing journey	Policy 11: Mobility as a Service and increased use of peer to peer car sharing which will help reduce the number journeys made by car. To do this we are harnessing innovation within our transport system through investing up to £2 million over three years to develop 'Mobility as a Service' (MaaS) in Scotland. We will grant funding CoMoUK to increase awareness of the role and benefits of shared transport and looking at the barriers to uptake of car clubs. We will provide support for travel planning through Travelknowhow Scotland, which is an online resource which offers employers access to sustainable travel planning tools to develop and implement workplace Travel Plans and encourage ride-sharing in order to start changing travel behaviour within organisations.	Overlapping/reinforcing measure
	Policy 12: We will work to improve road safety, ensuring people feel safe with appropriate measures in place to enable that. We will publish Scotland's Road Safety Framework to 2030, following consultation on an ambitious and compelling long-term vision for road safety where there are zero fatalities or serious injuries on Scotland's roads by 2050.	Overlapping/reinforcing measure
	Policy 13: We are committed to taking forward policy consultation in advance of drafting supporting regulations and guidance to enable local authorities to implement workplace parking levy schemes that suit their local circumstances.	Overlapping/reinforcing measure

Table 8-17e. Policy packages for the Transport sector – T5

Policy Package	Policy	Categorisation
T5 Promotion of ULEV (cars and vans)	Policy 1: We will consider and develop new financing and delivery models for electric vehicle charging infrastructure in Scotland and working with the Scottish Future Trust to do so.	Overlapping/reinforcing measure
	Policy 2: We have invested over £30m to grow and develop the ChargePlace Scotland network which is now the 4th largest in the UK. We will continue to develop the capacity of the electric vehicle charging network.	Overlapping/reinforcing measure
	Policy 3: Our Low Carbon Transport Loan has provided over £80m of funding to date to support the switch to low carbon vehicles. We will continue to support the demand for ultra-low emission vehicles (ULEVs) through our Low Carbon Transport Loan scheme, which is now being expanded to include used electric vehicles.	Key policy
	Policy 5: Continue to promote the benefits of EVs to individuals and fleet operators (exact nature of promotion to be decided annually).	Overlapping/reinforcing measure
	Policy 6: We will work with public bodies to phase out the need for any new petrol and diesel light commercial vehicles by 2025.	Key policy
	Policy 9: We will continue to invest in innovation to support the development of ULEV technologies and their adoption.	Supporting measure
	Policy 10: Take forward the initiatives in respect of connected and autonomous vehicles set out in A CAV Roadmap for Scotland.	Overlapping/reinforcing measure
	Policy 11: With local authorities and others, evaluate the scope for incentivising more rapid uptake of electric and ultra-low emission cars and vans.	Overlapping/reinforcing measure

Table 8-18f. Policy packages for the Transport sector – T6

Policy Package	Policy	Categorisation
T6 Promotion of ULEV (cars and vans) in public sector fleets	Policy 4: We will continue to promote the uptake of ULEVs in the taxi and private hire sector.	Overlapping/reinforcing measure
	Policy 7: We will support the public sector to lead the way in transitioning to EVs, putting in place procurement practices that encourage EVs. In the Programme for Government we committed to work with public bodies to phase out the need for any new petrol and diesel light commercial vehicles by 2025.	Key policy
	Policy 8: Create the conditions to phase out the need for all new petrol and diesel vehicles in Scotland's public sector fleet by 2030.	Key policy

Table 8-19g. Policy packages for the Transport sector – T7-8

Policy Package	Policy	Categorisation
T7 Promotion of low emission heavy duty vehicles	Policy 1: To support businesses we will establish a Zero Emission heavy duty vehicle programme and will invest in a new zero drive train testing facility in 2021.	Key policy
	Policy 2: Explore the development of green finance models to help business and industry to invest in new road transport technologies.	Supporting measure
	Policy 3: We will engage with industry to understand how changing technologies and innovations in logistics (including consolidation centres) can help to reduce carbon emissions, particularly in response to the increase in e-commerce.	Supporting measure
	Policy 4: Continue to investigate the role that other alternative fuels, such as hydrogen, and biofuel can play in the transition to a decarbonised road transport sector. Consider the scope for testing approaches to alternative fuels infrastructure and supply.	Supporting measure
	Policy 5: Launched the new Hydrogen Accelerator Programme to attract technical experts to help scale up and quicken the deployment of hydrogen technologies across Scotland.	Supporting measure
T8 Promotion of ultra-low or zero emission buses	Policy 1: We have introduced a revised green incentive of the Bus Service Operators Grant.	Key policy
	Policy 2: We launched a £9 million Scottish Ultra Low Emission Bus Scheme (SULEBS).	Overlapping/reinforcing measure
	Policy 3: In the context of the National Transport Strategy Delivery Plan and Transport Act, we will examine the scope for climate change policies, in relation to buses, across the public sector in high-level transport legislation strategies and policies.	Supporting measure
	Policy 4: We will work to align government financial support of £120 million over the next 5 years with private sector investment to decarbonise the bus sector.	Key policy

Table 8-20h. Policy packages for the Transport sector T9-10

Policy Package	Policy	Categorisation
T9 Promotion of low or zero emission aircrafts and SAF	Policy 1: We will aim to create the world's first zero emission aviation region in partnership with Highlands and Islands Airports Limited (HIAL). This will include taking action to decarbonise airport operations in the HIAL region.	Key policy
	Policy 2: We will begin trialling low or zero emission planes in 2021.	Supporting measure
	Policy 3: The Scottish Government will continue to engage with Aviation sector to encourage sustainable growth post COVID-19.	Overlapping/reinforcing measure
	Policy 4: Explore the potential for the purchase of zero/low emission aircraft by the Scottish Government, for lease back to operators, with more detailed assessment in the forthcoming Aviation Strategy.	Supporting measure
	Policy 5: Explore options for incentivising the use of more sustainable aviation fuel as we develop our Aviation Strategy, recognising that significant levers in this area are reserved.	Overlapping/reinforcing measure
T10 Promotion of low or zero emission ferries	Policy 1: Continue to examine the scope for utilising hybrid and low carbon energy sources in the public sector marine fleet as part of our vessel replacement programme.	Key policy
	Policy 2: Working with the UK Government to support proposals at the International Maritime Organisation (IMO) to significantly lower shipping carbon emissions in the global sector, including the option of introducing a global levy on marine fuel to fund research in cleaner technologies and fuels	Supporting measure

Table 8-21i. Policy packages for the Transport sector T11-12

Policy Package	Policy	Categorisation
T11 Promotion of alternative fuel infrastructure in ports	Policy 1: Working with individual ports and the British Ports Association to consider a process for encouraging shared best practice initiatives for reducing emissions across the sector.	Overlapping/reinforcing measure
	Policy 2: Working with the ports sector and with its statutory consultees through the Harbour Order process to ensure future port developments are environmentally underpinned.	Supporting measure
T12 Passenger rail decarbonisation	Policy 1: Our commitment to decarbonise (the traction element of) Scotland's railways by 2035 will be delivered through investment in electrification and complementary alternative traction systems. Transport Scotland has published the Rail Services Decarbonisation Action Plan (July 2020) which will be updated as appropriate. Work is ongoing by industry partners to develop the initial schemes.	Key policy
	Policy 2: We will establish an international rail cluster in Scotland to unlock supply chain opportunities using the interest at Longannet as a catalyst. This will be built around existing strengths in rail in Scotland and will seek to enhance the innovation and supply chain in the decarbonisation of our rolling stock and wider network.	Supporting measure
	Policy 3: Continue to deliver our Rail Freight Strategy.	Overlapping/reinforcing measure

8.2.4 Variation across scenarios

Higher economic growth is assumed to increase traffic, as evidence suggests that there is a correlation between passenger transport and GDP growth.[49] So, while all scenarios assume that there is some level of reduction in travel demand, in the high growth scenario the GHG reduction from Policy T2: travel demand management is smaller.

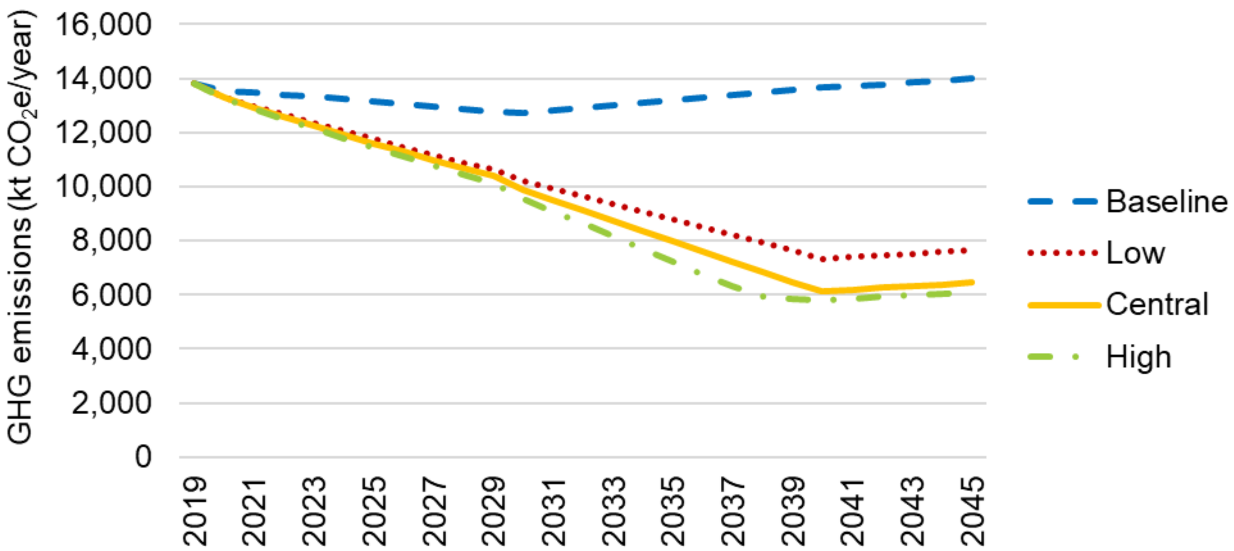
On the other hand, higher economic growth is assumed to result in greater affordability of EVs; it also increases the amount of public funding available to support the transition. So, in the high growth scenario, we have assumed that ULEV uptake, network electrification, use of SAF and low emission ferries will all increase.

8.3 Emissions Projections

8.3.1 Phase 1 results

Total CO_2 emissions from the transport sector are expected to drop from around 13.8 $MtCO_2$ in 2019 to around 6.4 $MtCO_2$ by 2040. The remaining emissions by 2040 would be mostly coming from aviation and shipping. The existing policy measures to decarbonise domestic aviation and shipping would only deliver a limited reduction in CO_2 emissions.

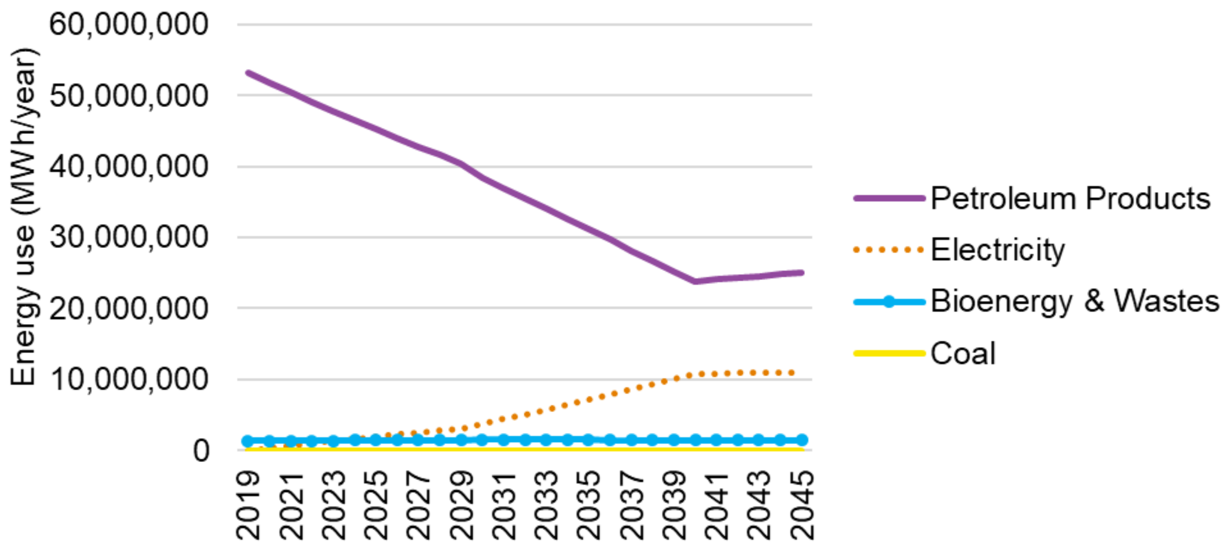
Figure 8-1: Phase 1 emission projections (in $ktCO_2e$) by scenario



The transport sector is expected to reduce its reliance on petroleum products as it transitions to low and zero carbon technologies. The expected electrification of road transport by 2040 would increase the electricity consumption of this sector. Since electric powertrains tend to be more energy efficient than internal combustion engines, the overall energy consumption is expected to drop substantially.

[49] European Environment Agency, *'Correlation in growth of passenger transport vs GDP growth'* (2012). Available at: https://www.eea.europa.eu/data-and-maps/figures/correlation-in-growth-of-passenger-transport-vs-gdp-growth

Figure 8-2: Phase 1 energy use projections in the central scenario (in MWh)

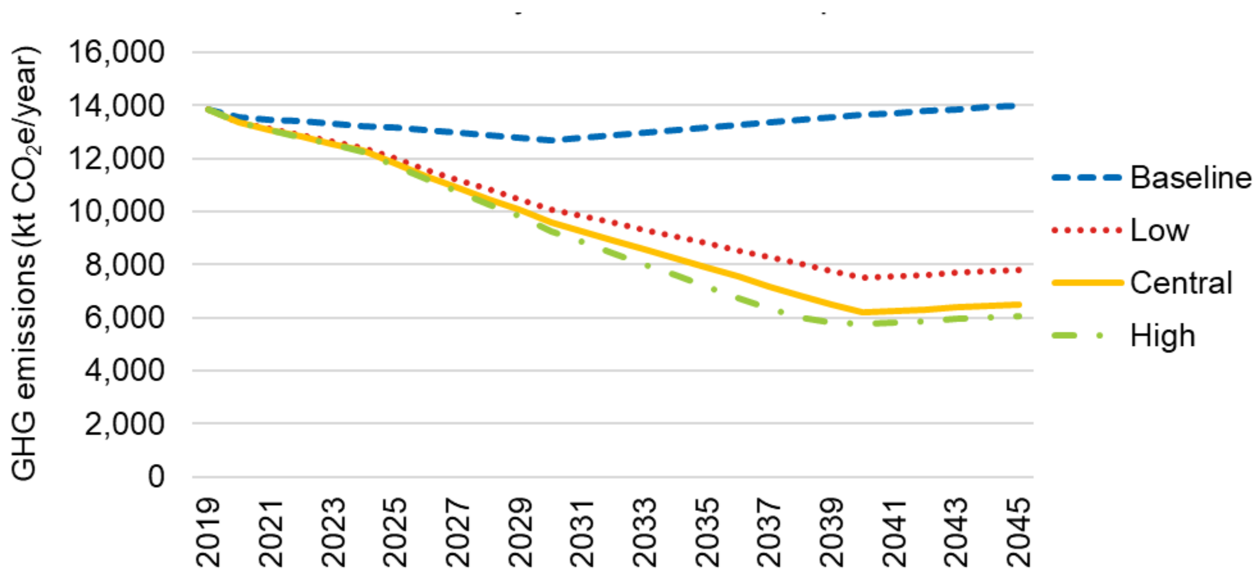


8.3.2 Phase 2 results

It is important to note that the main difference with the Phase 1 modelling assumptions is the increased car traffic reduction by 2030 (outcome 1), which captures a full achievement of the traffic reduction target. The full decarbonisation of internal flights within Scotland (outcome 5), which was not included in Phase 1, represents a small proportion of overall emissions from aviation and, hence, it is not expected to alter emission projections significantly.

The resulting emission projection by 2050 under Phase 2 modelling assumptions is displayed below. Total CO_2 emissions from the transport sector are expected to drop from around 13.8 $MtCO_2$ in 2019 to around 6.2 $MtCO_2$ by 2040. This projection is very similar to that of Phase 1.

Figure 8-3. Phase 2 emission projections (in $ktCO_2e$) by scenario



8.3.3 Comparison of Phases 1 & 2

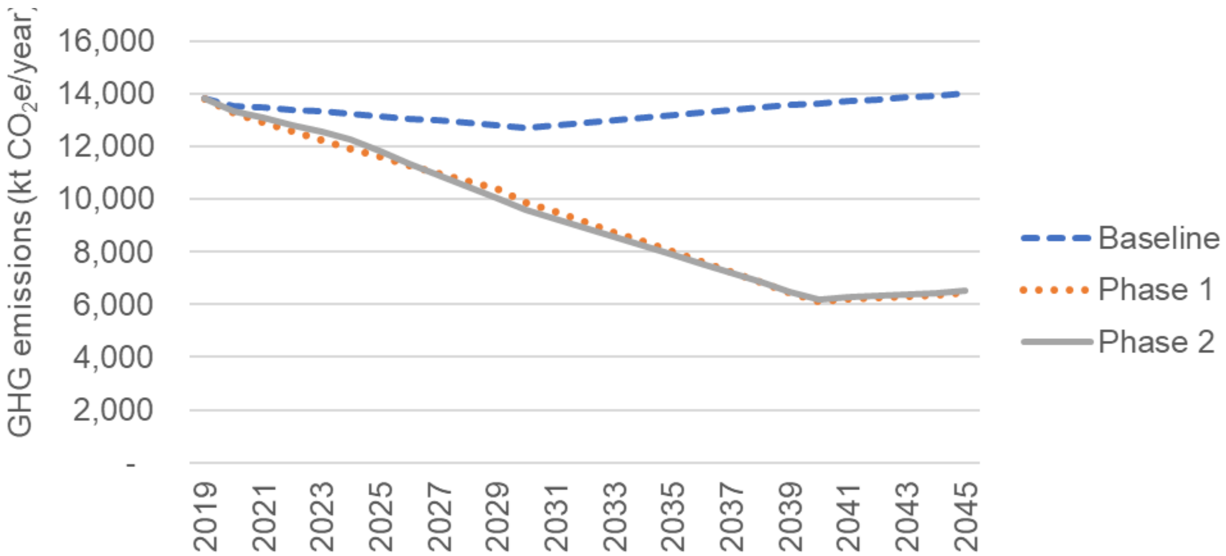
The table below provides a comparison of the projected emissions for Phase 1 and Phase 2 (in ktCO_2e) and by scenario. Emissions in 2030 and 2035 are lower under Phase 2 modelling assumptions due to the effect of the higher car traffic reduction by 2030. Differences in 2020 and 2025 between Phase 1 and Phase 2 assumption are mostly due to the additional time granularity to describe the uptake of ULEV in Phase 2. Similarly, higher emissions in 2040 and 2045 under Phase 2 relate to the more refined time granularity in Phase 2 modelling.[50] This is a limitation of the Phase 1 modelling approach and should be considered when comparing projections from Phase 1 and Phase 2.

[50] Average energy consumption per vehicle changes with transport activity levels within each period. This non-linearity introduces small differences in the estimation of cumulative energy and emission reductions under different modelling time steps.

Table 8-22. Emission projections for the transport sector under the baseline and under modelled scenarios, for both Phase 1 and Phase 2 (in $ktCO_2e$)

Phase	Scenario	Emissions ($ktCO_2e$)						
		2019	2020	2025	2030	2035	2040	2045
n/a	**Baseline**	**13,820**	**13,551**	**13,149**	**12,698**	**13,175**	**13,647**	**13,996**
1	**Central Growth**	**13,820**	**13,274**	**11,601**	**9,873**	**7,999**	**6,134**	**6,440**
	High Growth	13,820	13,246	11,446	9,543	7,240	5,803	6,097
	Low Growth	13,820	13,301	11,756	10,203	8,791	7,337	7,652
2	**Central Growth**	**13,820**	**13,349**	**11,805**	**9,585**	**7,880**	**6,197**	**6,505**
	High Growth	13,820	13,345	11,735	9,265	7,167	5,770	6,066
	Low Growth	13,820	13,374	11,985	10,074	8,799	7,494	7,810

Figure 8-4: Differences in emissions from the Transport sector between the modelling results from the Baseline scenario, and the Central scenarios in Phases 1 and 2



Note: The results from Phases 1 and 2 are visibly almost indistinguishable from each other because of the small magnitude of differences between them.

8.3.4 Emissions reduction by policy package (2032) – Phase 1 & 2

This section presents results on the contribution of each policy package (as described in Table 8-7) to emission reductions of each policy outcome considered in the model.

Results presented in Table 8-23 indicate that the promotion of ULEV for cars and vans (policy package T5) contribute the most to the overall emission reduction by 2032 across all scenarios (with 64% of total emission reduction). Travel demand policies (policy packages T1, T2, T3 and T4) and the promotion of ULEV for heavy duty vehicles (policy package T7) also represent a significant proportion of overall emissions reduction, with 9%

and 12% of the total reduction, respectively. Other policy packages have more limited contributions to the overall reduction of GHG emissions in the transport sector by 2032.

The total reduction of GHG emissions by 2032 is slightly higher under Phase 2 assumptions, compared to Phase 1. As above mentioned, the main difference between Phase 1 and Phase 2 relates to the achievement of the 20% car traffic reduction target by 2030 (i.e. full achievement in Phase 2 and 10% reduction in Phase 1). This means that the difference of around 200 ktCO_2e between the central scenario in Phase 2 and Phase 2 can be attributed to the effect of the more pronounced car traffic reduction in Phase 2.

Table 8-23. Emission reduction contributions (in ktCO_2e) of transport sector policy packages under model scenarios by 2032, with respect to the baseline

Policy Package	Emissions reductions by 2032 (ktCO_2e)					
	Phase 1			Phase 2		
	Central Growth	High Growth	Low Growth	**Central Growth**	High Growth	Low Growth
T1-4	-339	-170	-509	-678	-509	-678
T5	-2,403	-2,883	-1,922	-2,210	-2,652	-1,768
T6	-113	-136	-91	-113	-136	-91
T7	-445	-534	-356	-502	-603	-402
T8	-271	-325	-217	-271	-325	-217
T9	-39	-47	-32	-39	-47	-32
T10	0	0	0	0	0	0
T12	-143	-172	-115	-143	-172	-115
Total	**-3,754**	**-4,268**	**-3,241**	**-3,957**	**-4,443**	**-3,301**

8.4 Uncertainties

Due to the number of assumptions used, we suggest that the energy use and GHG emission projections are indicative but are sufficient to allow an informed debate about the future trajectory of emissions in the sector, and, to identify policies which are likely to deliver meaningful GHG reductions. There is a high level of uncertainty associated with the technical and economic characteristics of fuel-switching technologies, particularly for aviation and shipping sectors. In addition, there is a large uncertainty around transport activity levels in the years following the Covid-19 pandemic.

Overall, the level of uncertainty was estimated at 15% for road and rail transport and 20% for aviation and shipping.

8.5 Sensitivities

In the model, the uptake of zero emission technologies for road transport is conditioned by phase-out targets for internal combustion engine vehicles. As such, projections for road transport will be mostly affected by changes in road transport demand in the following years. Phase 2 modelling assumes the 20% traffic reduction target by 2030 is fully achieved, while the modelling of policies assumes only a partial reduction by 2030. The difference between Phase 1 and Phase 2 can be used to assess the sensitivity around car traffic trends. For aviation and maritime, the uptake of sustainable drop-in fuels (e.g. SAF for aviation or ammonia for maritime transport) is expected to be the main sensitivity parameter.

9. Waste sector

9.1 Sector Overview

9.1.1 Sector Background

Scotland has set ambitious emissions reduction targets in the waste and resources sector. Emissions in the Waste sector reached 1.5 $MtCO_2e$ in Scotland in 2019, which is a marked reduction from 5.8 $MtCO_2e$ in 1990.[51] With the aim to reduce these emissions to 0.9 million tonnes by 2025, and 0.7 million tonnes by 2030, Scotland faces significant challenges to meet its targets. The Climate Change Plan update (CCPu)[52] sets out four policy outcomes for the Waste sector and sets the following key commitments by 2025:

- End landfilling of biodegradable municipal waste
- Reduce the percentage of all waste sent to landfill to 5% and recycle 70% of all waste
- Double the number of landfill gas capture sites in Scotland that undertake investigative or development work (from 12 to 24 sites)
- Reduce food waste by 33% from the 2013 baseline

The first annual monitoring report against the CCPu was published in March 2021. While this report suggests progress is being made on outcomes (reduction in landfilled waste, biodegradable municipal waste to landfill), it concluded that it was ultimately too early to evaluate whether the Plan is on track to achieve the key policy outcomes for the Waste sector.

9.1.2 Subsectors Considered

The Waste sector was disaggregated into the following subsectors:

- Landfill
- Anaerobic digestion (AD)
- Composting
- Sewage & Wastewater
- (Incineration)

The CCPu mainly focuses on landfill, since this source is responsible for the largest contribution to the GHG emissions from the Waste sector, followed by wastewater treatment. Since all incineration of waste in Scotland is with energy recovery, emissions from this source are reported in the energy sector and have not been modelled in this sector.

[51] Greenhouse Gas Inventories for England, Scotland, Wales & Northern Ireland: 1990-2019

[52] Scottish Government, '*Update to the Climate Change Plan 2018 – 2032: Securing a Green Recovery on a Path to Net Zero'* (16 Dec 2020). Available at: https://www.gov.scot/publications/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/pages/1/

9.1.3 Data Sources

The main data sources used to undertake the assessment of the Waste sector are detailed in Table 9-1 below.

Table 9-1. A summary of the different data sources used in the assessment of the Waste sector

Purpose	Data used	Comment
GHG inventory for Scotland	UK National Atmospheric Emissions Inventory (UK NAEI)	GHG inventory for Scotland needed to estimate impacts of policies on emissions.
Energy consumption in Scotland	UK National Atmospheric Emissions Inventory (UK NAEI)	Energy consumption by sub-sector in Scotland needed to estimate impacts of policies on energy use.
Total waste generated	SEPA 2018	Waste from all sources in Scotland – summary data 2018
Waste landfilled	SEPA 2019	Total amount of landfilled waste and biodegradable landfilled waste

Note that some of the data sources have been updated since the analysis in this report was originally undertaken.

9.1.4 Underlying Drivers of Energy & Emissions

The main underlying driver of emissions in the Waste sector is the amount of waste generated and treated. Different waste streams and treatment methods have different impacts on emissions. The disposal of solid waste to landfill is the main source of methane generated for this sector. Methane is a potent greenhouse gas with a global warming potential (GWP) 28 times higher than that of CO_2; it accounts for the majority of GHG emissions from the Waste sector. Therefore, the amount of biodegradable waste, the fraction responsible for generating methane, and the total amount of landfilled waste are the main underlying drivers of growth in energy use and emissions in the Waste sector. With regards to wastewater treatment (the second largest source of emissions for the sector), the main underlying drivers of growth in energy use and emissions are population and GVA (Gross Value Added). The amount of domestic wastewater is likely to increase in line with population while the amount of industrial wastewater may be linked to economic growth, measured by GVA. Energy consumption in the Waste sector is negligible in comparison to total national energy consumption.

When estimating the impact of policy measures on emission generation and energy use, the following assumptions were made:

- 4% growth in the amount of biological waste treated via anaerobic digestion based on the activity data from the period 2016-2020
- 0% growth in the amount of biological waste treated via composting based on the activity data from the period 2016-2020

- 1% growth for domestic wastewater based on emissions from the period 2016-2020
- 0% growth for industrial wastewater on emissions from the period 2016-2020

Since production of methane from the disposal of solid waste to landfills can continue for many years after their closure, this source needs to be modelled separately. A modified version of MELMod, the model used to calculate methane generation in the UK GHG inventory, was run to estimate the impact of reducing and eventually banning the disposal of biodegradable waste. Methane emitted to the atmosphere is then calculated subtracting the total amount of methane collected (total of methane utilised to produce energy and methane flared) and the methane oxidised in the landfill cover from the total amount of methane generated. Since utilised and flared methane depends on several variables difficult to model, the following assumptions were made:

  - The 2016-2020 average collection efficiency of 63% was used to estimate the amount of methane collected from the methane generated and use to calculate the methane emitted.
  - A conservative approach was taken to assume that the amount of flared methane, as calculated above, already included the contribution from the additional landfill gas flared from closed sites, which cannot be estimated at the moment.

9.2 Policy Measures and Outcomes Modelled

9.2.1 Phase 1 – Policy Measures

For the Waste sector, there were 16 policies/proposals to be assessed. Two proposals were deemed unquantifiable (especially those related to reduce waste and establish a more circular economy), due to a lack of data on how to quantify their impact and consequently incorporate them in the model for the GHG projections. These were excluded from the assessment.

Due to a lack of available data, it was not possible to assess some policies together (to ensure interactions between similar policies/proposals were captured) despite the fact they target similar outcomes. For example, the policies addressing landfilling of biodegradable municipal waste and reducing food waste have a combined effect on reducing methane generation from landfilled waste, but data for household and non-household food waste is available only for 2018.

Table 9-2 below shows the packaging of policies into key themes, and the quantifiable targets informing the assessment. Reducing biodegradable waste to landfill (including historical trend) is considered the main driver for reducing Waste Management sector emissions.

Table 9-2a: A summary of CCPu policies for the Waste sector

Theme	Quantifiable targets	Relevant policies / strategies / actions
Reduction in biodegradable waste sent to landfill	Overall target: End landfilling of biodegradable municipal waste by 2025. Related targets: • Reduce percentage of all waste sent to landfill to 5% by 2025 • Recycle 70% of all waste by 2025	• Develop a new route map to reduce waste and meet waste and recycling targets for 2025 • Develop a post-2025 route map for the waste and resources sector • Establish a £70m fund to improve local authority recycling collection infrastructure • Promote reuse and recycling ensure separate collection of textiles by 2025 • Ensure bio-waste (e.g., garden waste) separation and recycled at source, or separate collection to avoid mixing with other types of waste by 2023 • Extend the ban on biodegradable municipal waste to landfill to biodegradable non-municipal wastes • Evaluate the Household Recycling Charter and review its Code of Practice with COSLA as a key step in developing a future model of recycling collection • Develop electronic waste tracking
Reduction in food waste	Overall target: reduce food waste by 33% from the 2013 baseline by 2025	• Considering a mandatory national food waste reduction target and mandatory reporting of Scotland's food surplus and waste by food businesses. • Consulting on the current rural exemption and food separation requirements for food waste collections • Support the development and implementation of an NHS Scotland national action plan on food waste • Develop best practice guidance for public sector procurement teams for a more transparent supply chain • Support public engagement and communications to enable the public to make changes in their choices and behaviours around food and food waste, in partnership with Zero Waste Scotland

Table 9-3b: A summary of CCPu policies for the Waste sector - continued

Theme	Quantifiable targets	Relevant policies / strategies / actions
Reduction in emissions from closed landfill sites	N/A – no quantifiable targets: 12 closed sites have been identified to capture landfill gas Note: the amount of flared landfill gas depends on several variables, and it is expected to decrease. Additional information on the sites is required to estimate quantifiable targets	• In association with SEPA and the waste industry double the number of landfill gas capture sites (from 12 to 24 sites) • Accelerate Landfill Gas Capture and Landfill Legacy Management • Note: any targets aimed at increasing the amount of flared landfill gas will contribute to reduce emissions from landfills

9.2.2 Phase 2 – Outcomes

Through discussion with the Scottish Government, it was agreed that no further modelling would be undertaken for the Waste sector in Phase 2.

As is the case for other sectors, it is noted that further potential measures may be brought forward that could impact on emissions from the Waste sector which have not been included in this analysis. For example, the Food Waste Reduction Action Plan is being reviewed at the time of writing (April 2023) which may result in revised targets. The Scottish Government has also developed and consulted on proposals for a Route Map to deliver on 2025 targets and set out proposals for a Circular Economy Bill.

9.2.3 Summary of Policy Packages

The table below indicates which policies were found to have the biggest potential impact within each package, which policies overlap with (or reinforce) each other, and which policies act as supporting measures.[53]

[53] The following descriptions have been used:

- **Key policies** are those that are expected to have the largest direct, tangible impacts on emissions, relative to others within each package.

Policies related to the diversion of biodegradable waste from landfills, such as in policy package W1 and W3, are expected to have a greater impact on emission reduction for the waste sector. Banning of biodegradable municipal waste and introducing a mandatory national food waste reduction target will reduce emissions, since biodegradable waste is responsible for a large fraction of methane emissions, when disposed to landfill. Although capturing landfill gas has been an effective way to reduce methane emissions over the last decades, it is difficult to establish the impact of the proposal as described in package W2.

- **Supporting measures** are those that will not have a direct, quantifiable impact on emissions, but may create an enabling environment or facilitate development of further policies/actions that will have a direct impact.
- **Overlapping/reinforcing measures** are those that interact with (and often contribute to the same activity impacts as) other policies - modelling these policies separately without consideration of interactions with other policies would incur double counting of emissions reductions.

Table 9-4a. Policy packages for the Waste sector W1

Policy Package	Policy	Categorisation
W1 Reducing total (and biodegradable) waste to landfill	Policy 1: End landfilling of biodegradable municipal waste by 2025	Key policy
	Policy 2: Reduce the percentage of all waste sent to landfill to 5% by 2025	Key policy
	Policy 3: Recycle 70% of all waste by 2025	Overlapping/reinforcing measure
	Policy 4: Developing a new route map to reduce waste and meet our waste and recycling targets for 2025 in a way that maximises their carbon savings potential	Supporting measure
	Policy 5: Developing a post-2025 route map for the waste and resources sector, identifying how the sector will contribute towards Scotland's journey towards net zero in the period to 2030 and beyond	Supporting measure
	Policy 6: Establishing a £70m fund to improve local authority recycling collection infrastructure	Overlapping/reinforcing measure
	Policy 7: In line with EU requirements, further promoting reuse and recycling ensure separate collection of textiles by 2025; and ensuring that bio-waste (e.g. garden waste), is either separated and recycled at source, or is collected separately and is not mixed with other types of waste by 2023	Overlapping/reinforcing measure

Table 9-5b. Policy packages for the Waste sector W2-3

Policy Package	Policy	Categorisation
W2 Landfill gas capture	Proposal 1: Landfill gas capture on closed sites: in association with SEPA and the waste industry, double the number of landfill gas capture sites that undertake investigative or development work (from 12 to 24 sites) by 2025, in order to harness energy generated from landfill gas capture and maximise other circular economy opportunities. SEPA has already identified 12 sites for potential investigative work.	Key policy
W3 Food waste reduction	Policy 1: Improving monitoring and infrastructure by considering a mandatory national food waste reduction target and mandatory reporting of Scotland's food surplus and waste by food businesses	Key policy
	Policy 2: Consulting on the current rural exemption and food separation requirements for food waste collections, to help break down barriers to food waste reuse and recycling	Supporting measure
	Policy 3: Supporting leadership, innovation, effectiveness and efficiency in Scotland's public, private and hospitality sectors by expanding pilot programmes across the education sector and public sector buildings	Supporting measure
	Policy 4: Support the development and implementation of an NHS Scotland national action plan on food waste	Supporting measure
	Policy 5: Develop best practice guidance for public sector procurement teams to drive new ways of working and more transparent supply chains.	Supporting measure
	Policy 6: A sustained approach to public engagement and communications to enable the public to make changes in their choices and behaviours around food and food waste, in partnership with Zero Waste Scotland.	Supporting measure

9.2.4 Variation across scenarios

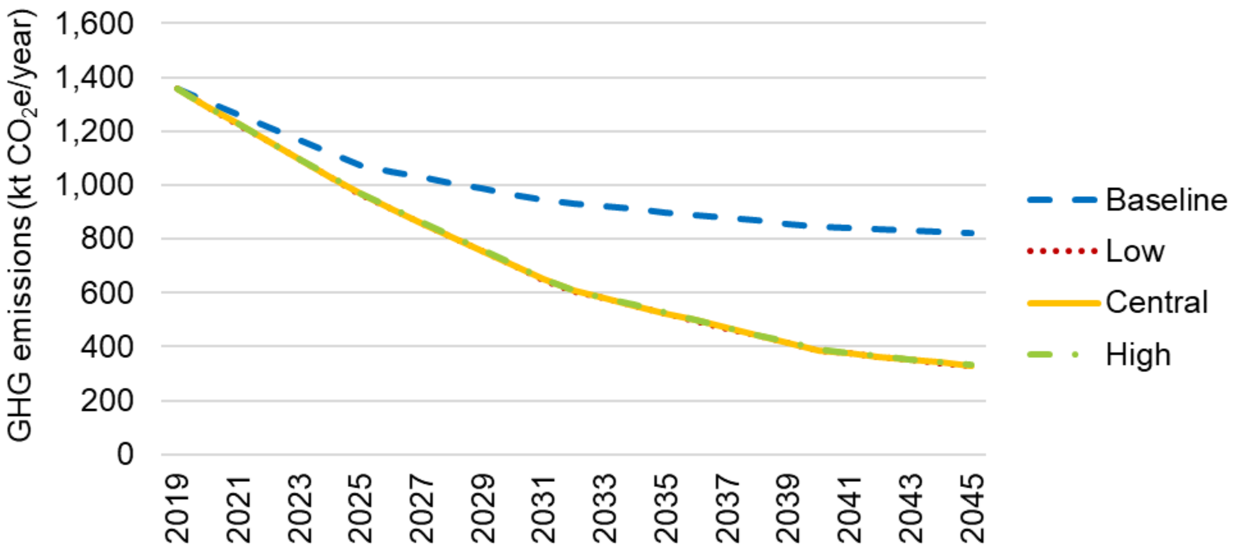
It is assumed that the ban on biodegradable waste sent to landfill is unaffected by different economic growth scenarios. For the other measures, however, it is assumed that low economic growth will result in lower policy implementation, and high economic growth will result in greater policy achievement.

9.3 Emissions Projections

9.3.1 Phase 1 results

Total CO_2e emissions from the Waste sector (shown in Figure 9-1) are expected to decline from 1.5 $MtCO_2e$ in 2019 to around 0.70 $MtCO_2e$ in 2030, and around 0.33 $MtCO_2e$ in 2045. The remaining emissions would be mostly coming from wastewater and composting.

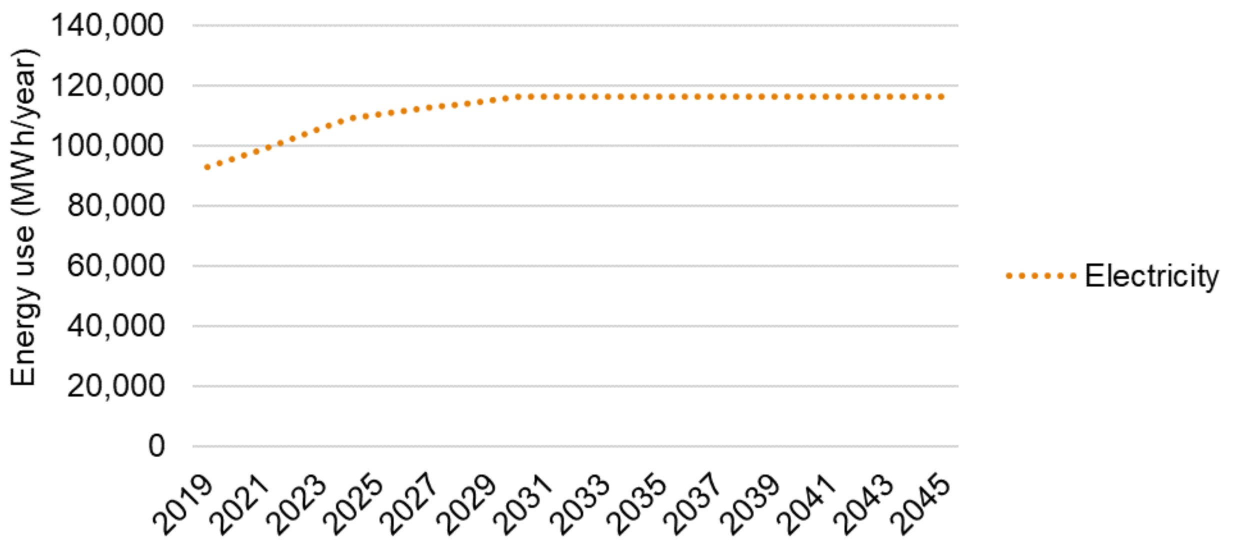
Figure 9-1: Phase 1 emissions projections under all modelled scenarios for the Waste sector as a whole



Note: The results from the three growth scenarios are visibly almost indistinguishable from each other because of the small magnitude of differences between them.

Energy used in the Waste sector is small compared to other sectors. The electricity consumption of this sector is expected to slightly increase and then plateau from 2030, as shown in Figure 9-2.

Figure 9-2: Phase 1 energy consumption projections under the modelled central scenarios for the Waste sector as a whole



9.3.2 Phase 2 results

As stated previously, no additional modelling was undertaken.

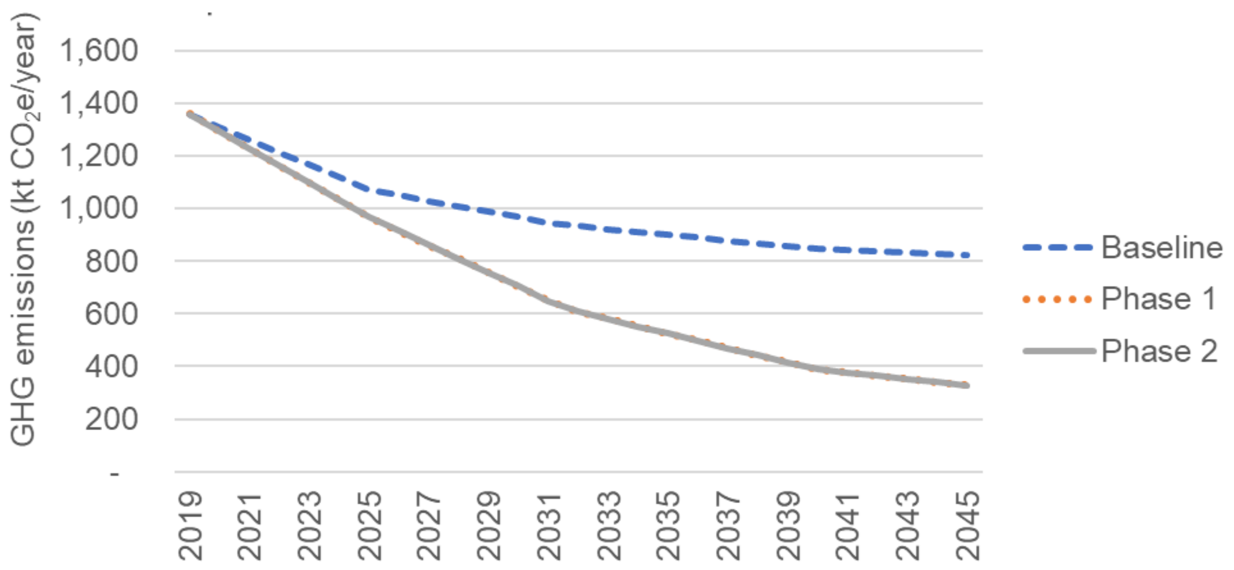
9.3.3 Comparison of Phases 1 & 2

The table below provides a comparison of the projected emissions for Phase 1 and Phase 2 (in $ktCO_2e$) and by scenario.

Table 9-6. Emission projections for the Waste sector under the baseline and under modelled scenarios, for both Phase 1 and Phase 2 (in $ktCO_2e$)

Phase	Scenario	Emissions ($ktCO_2e$)						
		2019	2020	2025	2030	2035	2040	2045
n/a	**Baseline**	**1,357**	**1,309**	**1,071**	**966**	**900**	**845**	**822**
1	**Central Growth**	**1,358**	**1,293**	**966**	**704**	**525**	**388**	**329**
	High Growth	1,358	1,293	968	706	527	390	331
	Low Growth	1,358	1,292	965	702	523	385	327
2	**Central Growth**	**1,358**	**1,293**	**966**	**704**	**525**	**388**	**329**
	High Growth	1,358	1,293	968	706	527	390	331
	Low Growth	1,358	1,292	965	702	523	385	327

Figure 9-3. Differences in emissions from the Waste sector between the modelling results from the Baseline scenario, and the Central scenarios in Phases 1 and 2



Note: The results from Phases 1 and 2 are visibly almost indistinguishable from each other because of the small magnitude of differences between them.

9.3.4 Emissions reduction by policy package (2032) – Phase 1 & 2

This section presents results on the contribution of each policy package to emission reductions of each policy outcome considered in the model. Packages W1 and W3 (see Section 9.2.3 for package details) interact, so are considered together here. Package W1 (focused on reducing biodegradable waste and total waste sent to landfill) delivers all of the expected emissions reductions quantified here for the Waste sector.

For package W2, it was not possible to analyse this policy separately due to the lack of data – it is essentially intrinsically modelled. Methane emissions from closed landfills, as described in package W2, are likely to be smaller than from active landfills, since it is assumed the a large fraction of organic matter has already undergone the degradation process responsible for methane production. Based on the results following the investigative work on those identified 12 sites, it should be possible to determine the potential emission reduction associated with the measure. As part of this project, the impact of capturing landfill gas from 12 additional sites (W2) has been taken into account as part of the modelling for emission from landfills. This based on the quantity currently captured in Scotland and its impact is quite modest.

Table 9-7. Emission reduction contributions (in $ktCO_2e$) of Waste sector policy packages under model scenarios by 2032, with respect to the baseline

Policy Package	Emissions reductions by 2032 (kt CO_2e)					
	Phase 1			Phase 2		
	Central Growth	High Growth	Low Growth	Central Growth	High Growth	Low Growth
W1+W3	-325	-323	-327	-325	-323	-327
W2	0	0	0	0	0	0
Total	**-325**	**-323**	**-327**	**-325**	**-323**	**-327**

9.4 Uncertainties

Due to the number of assumptions used, we suggest that the energy use and GHG emission projections are indicative but are sufficient to allow an informed debate about the future trajectory of emissions in the sector, and, to identify policies which are likely to deliver meaningful GHG reductions. For example, there is a high level of uncertainty associated with the amount of utilised and flared landfill gas, the effect and the implementation of waste diversion, and the technical and economic implementation of several proposals, whose impact cannot be assessed.

9.5 Sensitivities

The two sources with the largest methane emissions in the Waste sector are landfills, and wastewater treatment.

Waste to landfill:

- The magnitude of GHG emissions in the waste to sector are sensitive to:
  - The quantities of biodegradable waste generated, and so by inference, the split between inert and biodegradable waste in waste arisings
  - The quantities of biodegradable waste sent to landfill. Emissions can be reduced by diverting biodegradable to AD and composting routes and using methane capture at landfills.
- Although there are large uncertainties in the lifetime methane emissions per tonne of waste disposed to landfill, food waste and garden waste generally have the highest biodegradable component that is responsible for methane emissions.

Wastewater treatment

- In this study, the emissions have assumed to scale according to changes in population and GVA.

Waste incineration

- Waste combustion is not considered in this sector as part of this study.

10. Negative Emission Technologies (NETs)

10.1 Sector Overview

10.1.1 Sector Background

Scotland is unlikely to meet its CO_2 reduction targets without the implementation of some form of Negative Emissions Technologies (NETs), including direct air carbon capture and storage (DAC) and bioenergy with carbon capture and storage (BECCS). BECCS applications include BECCS power, BECCS hydrogen, BECCS in industry, BECCS biofuels and biogas, and BECCS energy from waste (EfW). The importance of BECCS and DACCS for Scotland to achieve net zero targets has been highlighted by the CCC's Sixth Carbon Budget. BECCS and DACCS are needed in Scotland to balance residual emissions in 2030 and 2045.[54]

The CCPu NETs envelopes are 3.8 Mt CO_2e/year in 2030 and 5.7 Mt CO_2e/year in 2032. The majority of the 5.7 Mt CO_2e/year target comes from BECCS with around 0.5 CO_2e/year coming from DACCS. This shows the importance of bioenergy with carbon capture and storage for Scotland as a NET. Increased interest in NETs in Scotland is evident. For example, the Acorn CCS project will explore the potential to develop a large-scale DACCS facility in Scotland. Partners in the Acorn project have announced a further £1bn in investment[55] and as of spring 2023 the Scottish Government has pushed the UK Government for additional funding.[56] However, policies to encourage the development of NETs are needed in Scotland in order to reduce revenue uncertainty and promote investment.

10.1.2 Subsectors Considered

The NETs sector was disaggregated into two subsectors, BECCS and DAC. There are other sectors which fall under NETs such as afforestation, reforestation and forest management. The CCPu considers DACCS and BECCS within the NETs sector; natural sequestration methods such as afforestation which may result in negative emissions are covered by the LULUCF sector.

10.1.3 Data Sources

The baseline energy consumption and associated emissions for the NETs sector are zero, as there are currently no NETs plants in Scotland. Hence, there is no baseline energy consumption data required for this subsector. In order to carry out the calculations described in the 'Underlying drivers of energy and emissions' section, the following data sources and documents were utilised:

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[54] In this study, all emissions from electricity are allocated to the Electricity sector. Emissions from electricity in the sectors that *use* electricity, including the NETs sector, are zero.

[55] Link to an article on the Ineos website https://www.ineos.com/news/shared-news/ineos-grangemouth-moves-forward-on-the-next-phase-of-its-journey-to-reduce-greenhouse-gas-emissions-to-net-zero-by-2045-with-further-investment-in-excess-of-1-billion/

[56] Link to a letter on the Scottish Government website https://www.gov.scot/publications/carbon-capture-letter-to-uk-government/

Table 10-1: Data sources used within the NETs sector

Purpose	Data used	Comment
GHG inventory for Scotland	UK National Atmospheric Emissions Inventory (UK NAEI)	GHG inventory for Scotland needed to estimate impacts of policies on emissions.
Quantifying the impacts of CCPu policies/outcomes	Key data sources: - Assessing the Cost Reduction Potential and Competitiveness of Novel (Next Generation) UK Carbon Capture Technology, Benchmarking State-of-the-art and Next Generation Technologies, BEIS, Wood, 2018 - Greenhouse gas reporting: conversion factors 2022, BEIS - Negative Emissions Technologies and Reliable Sequestration: A Research Agenda (2019), National Academies, Sciences Engineering Medicine	N/a

10.1.4 Underlying Drivers of Energy & Emissions

The underlying driver of energy consumption within the NETs sector consists of the operation of the NETs plants. The form of BECCS considered is BECCS power, as this the technology with one of the highest TRLs at the current time. Other forms of BECCS, such as BECCS biomethane, may also progress quickly due to the high purity CO_2 streams that are produced, however less data is currently available in literature to incorporate these into the model. The energy consumption for BECCS power and DAC is predominantly in the form of electricity. The emissions factor utilised for electricity within the model is zero, and hence, no additional emissions are expected to arise from the operation of the NETs plants.

BECCS

A calculation was undertaken to estimate the capacity of a plant required to allow for 5.2 $MtCO_2$ to be captured per year. The calculation is based on a reference case plant of biomass post combustion with CCS for power generation. Assumption figures have been based on a comprehensive benchmarking CCS report[57]. It is common practice within BECCS for power generation to operate the CCS plants with electricity diverted from the

[57] Wood on behalf of the Department for Business, Energy & Industrial Strategy, *'Assessing the Cost Reduction Potential and Competitiveness of Novel (Next Generation) UK Carbon Capture Technology, Benchmarking State-of-the-art and Next Generation Technologies'* (2018). Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/864688/BEIS_Final_Benchmarks_Report_Rev_4A.pdf

electricity produced onsite, hence the electricity would be diverted from the electricity to the NETs sector. However, for the sake of simplifying the model, it is assumed that additional electricity from external sources will be utilised on the NETs plants, and hence this subsector. The calculated figures and assumptions are outlined in the table below.

Table 10-2: BECCS plant calculation

Metric		Value
Assumption	Load factor	80%
	Electrical conversion efficiency	35%
	CO_2 capture rate	90%
	Specific emissions from wood[58], $kgC0_2/KWh$	0.35
	Electricity input	15% of plant capacity
	CO_2 captured, Mt/year (2032 target)	5.2
Calculated figures	Plant capacity, MWe	825
	Annual, GWh	5,185
	Annual feed energy input, GWh	14,815
	Electricity input, MWe	110
	Annual emissions, tCO_2/year	5,777,778
	Annual electricity consumption once target is reached, MWh	866,667

DAC

The reference plant utilised for DAC calculations is one which utilises liquid solvent for CO_2 capture. This is because there is more data available on this type of plant than others, such as solid sorbent. An estimated figure based on existing literature[59] was used for the approximate energy consumption per unit of CO_2 captured.

[58] Department for Business, Energy & Industrial Strategy, *'Greenhouse gas reporting: conversion factors'* (2022). Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2022

[59] National Academies Press, *'Negative Emissions Technologies and Reliable Sequestration: A Research Agenda'* (2019). Available at: https://nap.nationalacademies.org/catalog/25259/negative-emissions-technologies-and-reliable-sequestration-a-research-agenda

Table 10-3: DAC plant calculation

Metric	Value
Energy requirements, GJ/tCO_2	10
CO_2 captured, Mt/year	0.5
Annual electricity consumption once target is reached, MWh	1,388,889

10.2 Policy Measures and outcomes Modelled

10.2.1 Phase 1 – Policy Measures

The key policy for developing the NETs sector is to ‘Support the development of NETs within Scotland’, which falls within Outcome 2: CCUS (Carbon Capture, Usage and Storage): the continued development of CCUS technologies and systems is prioritised to ensure these can be rolled out commercially and at scale by the late 2020s. All other policy proposals within outcome 2, and all policy proposals within outcome 1 are considered to be supporting measures towards the key policy of supporting the development of NETs technologies within Scotland. These supporting policy proposals are outlined in Table 10-4 below.

Table 10-4: Supporting policy measures within outcome 1 and 2 in the NETs sector

Outcome	Policy
Outcome 1: Detailed feasibility studies on NETS will assess the opportunities for negative emissions in Scotland, and identify applications with the greatest potential, including specific sites where possible.	Proposal 1: In 2021/22 carry out a detailed feasibility study of opportunities for developing NETS in Scotland ready for the early 2030s. This will identify specific sites and applications of NETS, including developing work to support policy on Direct Air Capture and its role within NETS in our future energy system.
	Proposal 2: From 2022, based on the outcomes of the feasibility work, we will provide support for commercial partners to develop NETS proposals including initial design and business cases.
	Proposal 3: Put in place a continual process to review the development of NETS and progress against its envelope.
	Proposal 4: We will work with UK Government to ensure that they bring forward suitable mechanisms to support the development of NETS business cases in relevant sectors.
Outcome 2: CCUS (Carbon Capture, Usage and Storage): the continued development of CCUS technologies and systems is prioritised to ensure these can be rolled out commercially and at scale by the late 2020s	Proposal 1: Support the inclusion of NETS in the development of strategic, industry lead pathways for CCUS infrastructure in Scotland.
	Proposal 2: Funding through the Scottish Industrial Energy Transformation Fund to consider the development of NETs demonstrators.
	Proposal 3: Provide a focus on integrating NETS projects with CCS infrastructure through the Emerging Energy Technologies Fund.

The remaining policies fall under Outcome 3 and are shown in Table 10-5 below and are also considered to be supporting measures.

Table 10-5: Policy measures within outcome 3 in the NETs sector

Outcome	Policy
Outcome 3: Bioenergy: a cross-sectoral approach for the appropriate and sustainable use of biomass in energy applications is agreed and implemented (taking into account competing land and feedstock uses).	Policy 1: We will publish a Bioenergy Update in early 2021, laying out our current position and understanding of the role of bioenergy in the energy system and setting out in more detail how we will move forward.
	Policy 2: In 2021, building on the Bioenergy Update, we will establishing a cross sectoral Bioenergy Expert Working Group to consider and identify the most appropriate and sustainable use for bioenergy resources across Scotland. It will also assess the volume of bioenergy resources that we can grow or produce within Scotland and confirm the level of import that we believe is compatible with a sustainable global trade in bioenergy.
	Policy 3: By 2023, in time to inform the next Climate Change Plan, we will publish a Bioenergy Action Plan, incorporating the learning developed by the expert working group and our understanding of the options to use Bioenergy in both NETs and other applications.

The NETs sector in Scotland is acknowledged to still be within its infancy. As previously mentioned, NETs is an important sector in Scotland to contribute towards net zero targets. Many of the policies within this sector are therefore aimed at accelerating the development of NETs in Scotland, through measures including feasibility studies and developing appropriate support mechanisms. Detailed feasibility studies will need to consider:

- Identifying key policy enablers and potential actions based on emerging national GGR support mechanisms
- Assessment of build-out rates and supply chain limitations to understand whether deployment rates are reasonable
- Plant specific feasibility studies to prioritise short term efforts as well as creating the relevant literature on NETs and gathering necessary data, technology assessment and limitations, permitting requirements
- Bioresource availability
- Evaluation of costs

Although these supporting policies will not lead to a direct reduction in emissions, actions such as these are crucial to inform future policies that will provide a mechanism for NETs to develop in Scotland, and hence contribute to the NETs targets outlined within the CCPu.

Targets

The potential negative emissions reduction of the policies is modelled to reach the CCPu target for NETs. It was agreed with Scottish Government that the timeline for reaching the targets is expected to be revised, therefore the policy start date is 2033, and the expected completion date to reach the targets is 2040 It is then assumed that approximately 90% of this target is attributed to BECCS and the remaining 10% is attributed to DAC. The figures are as shown in the table below.

Table 10-6: NETs targets

Target, 2032 (revised to 2040)	Quantity
NETs	-5.7 $MtCO_2$
BECCS	-5.2 $MtCO_2$
DAC	-0.5 $MtCO_2$

Calculations were then carried out to estimate the associated electricity consumption of BECCS and DAC plants that would achieve the targets shown in Table 10-6.

10.2.2 Phase 2 – Policy Outcomes

No additional modelling was carried out for Phase 2 of this work, as no further quantifiable policies/targets could be identified.

10.2.3 Summary of Policy Packages

The table below indicates which policies were found to have the biggest potential impact within each package, which policies overlap with (or reinforce) each other, and which policies act as supporting measures.[60]

For the NETs sector, one key policy was identified, with two supporting measures.

[60] The following descriptions have been used:

- **Key policies** are those that are expected to have the largest direct, tangible impacts on emissions, relative to others within each package.
- **Supporting measures** are those that will not have a direct, quantifiable impact on emissions, but may create an enabling environment or facilitate development of further policies/actions that will have a direct impact.
- **Overlapping/reinforcing measures** are those that interact with (and often contribute to the same activity impacts as) other policies - modelling these policies separately without consideration of interactions with other policies would incur double counting of emissions reductions.

Table 10-7. Policy packages for the NETs sector

Policy Package	Policy	Categorisation
N1 Development of NETs	Policy 1: Support the development of NETs technologies within Scotland.	Key policy
	Proposal 2: Funding through the Scottish Industrial Energy Transformation Fund to consider the development of NETs demonstrators.	Supporting measure
	Proposal 3: Provide a focus on integrating NETS projects with CCS infrastructure through the Emerging Energy Technologies Fund.	Supporting measure

10.2.4 Variation across scenarios

The policy measure identified for each subsector, BECCS and DAC, includes supporting the development of NETs in Scotland, through the SIETF and EETF. An indication of how they are expected to change under each scenario is outlined below.

Table 10-8: Change in NETs growth under each scenario

Central	Low growth	High growth	Low hydrogen	High hydrogen
Baseline	Medium	High	Low	Medium

NETs are required for Scotland to reach its net zero targets, therefore, even in a low growth scenario, medium growth of NETs can still be expected. In a high growth scenario, there will be more emissions and hence more NETs will be required to balance residual emissions, resulting in high NETs growth in a high growth scenario. NETs are expected to be deployed in sectors which are harder to decarbonise, such as in industry. NETs are also expected in the power sector where it can be retrofitted onto existing biomass and EfW sites.

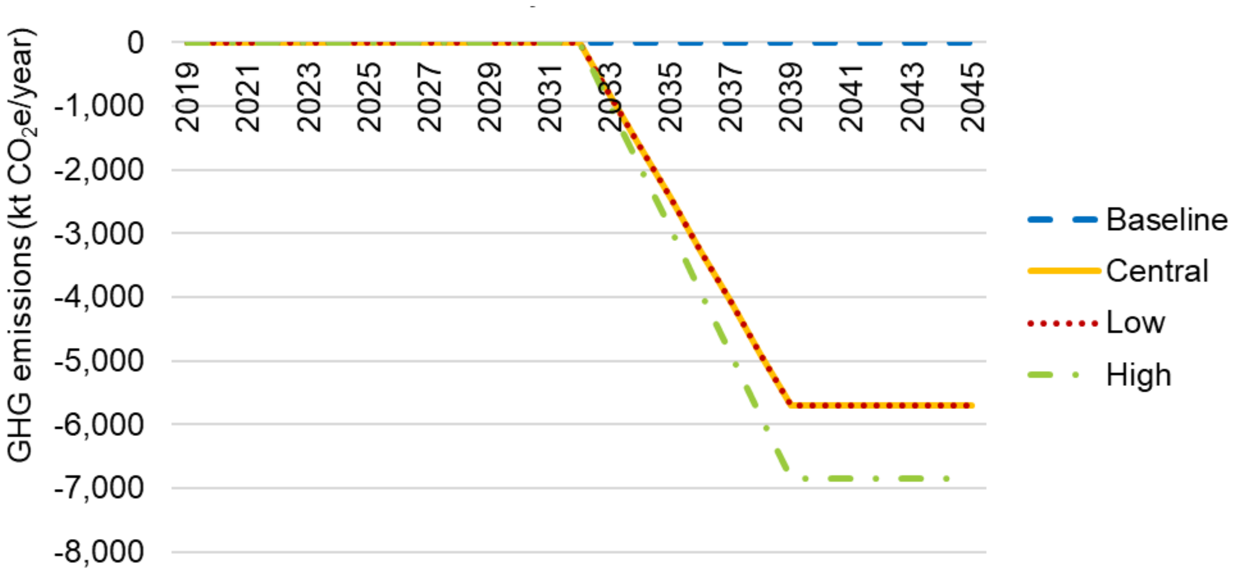
In a low hydrogen scenario, it is likely that hydrogen would not be predominantly produced through BECCS due to biomass resource availability and would more likely come from other sources such as renewables including solar PV and wind, or CCUS from fossil fuels. Hence in a low hydrogen scenario, low NETs growth is expected. In a high hydrogen scenario, there is a higher likelihood of hydrogen BECCS; however it can still be expected that hydrogen is predominately produced through other sources. Therefore, medium NETs growth can be expected in a high hydrogen scenario.

10.3 Emissions Projections

10.3.1 Phase 1 results

Figure 10-1 below represents the emissions in the NETs sector, should the targets be realised. As can be observed in Figure 10-1 below, the total emissions from the NETs sector in all scenarios (high, central, low) is expected to be zero until 2032. This acknowledges that several years are required to build a BECCS or DAC plant, as all of the emissions reduction in the sector is driven by the introduction of NETs plants which are capturing emissions from fuel sources or directly from the air. After 2032, NETs plants will begin to come online resulting in negative emissions from the sector, increasing up until 2040 when the NETs targets are expected to be reached. Emissions in the baseline scenario are zero all through to 2050, where it is assumed in this scenario that there is no growth in the NETs sector and hence no reduction in emissions associated with NETs.

Figure 10-1. NETs sector emissions projections under all scenarios (Phase 1)

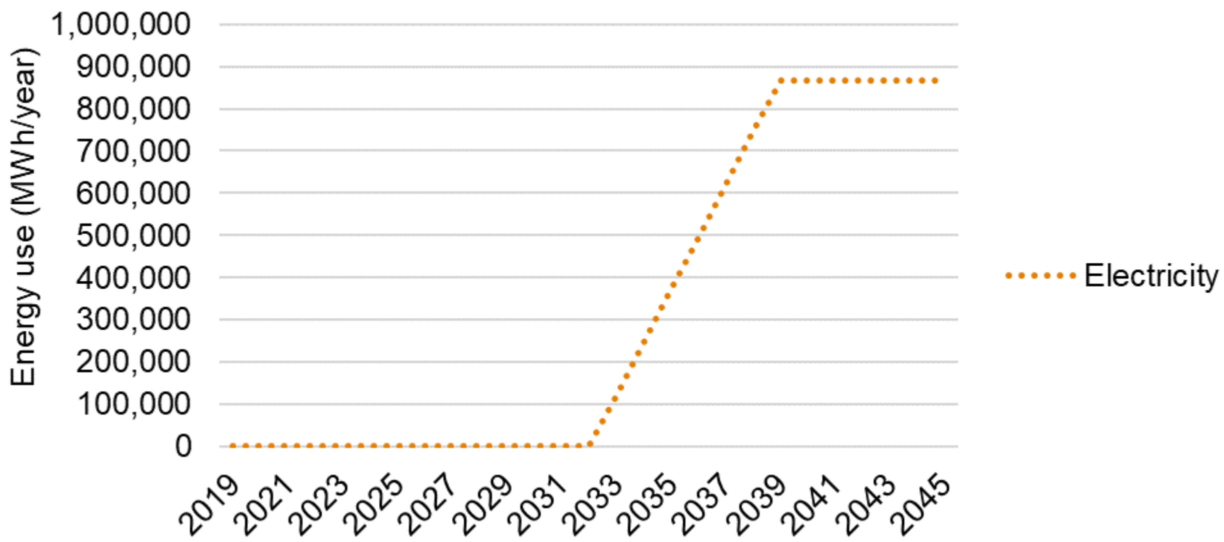


Note: The results from the three growth scenarios are visibly almost indistinguishable from each other because of the small magnitude of differences between them.

The central scenario follows the same trends as the low scenario. The reason for this is that, as explained previously, it is already widely understood that NETs are needed to balance residual emissions and hence reach net zero targets. Therefore, the NETs targets within the CCPu must be met in both cases in order for Scotland to reach net zero by 2045. In the high scenario, it has been assumed that there will be further growth in all sectors, some of which will already be low carbon and some which will not. Hence, further emissions reduction from the NETs sector will be required to balance residual emissions in sectors which are hardest to decarbonise.

As explained in the underlying drivers of energy and emissions section, the predominant energy use in the NETs sector consists of electricity, to operate the NETs plants. The energy profile of the sector follows a similar trend to the emissions, where electricity use is forecasted to increase from 2032 onwards once NETs plants begin to come online. Once the target is reached in 2040, the electricity use stabilises as there are no further NETs plants coming online.

Figure 10-2. NETs sector energy use in central scenario (Phase 1)



10.3.2 Phase 2 results

As stated previously, no additional modelling was undertaken.

10.3.3 Comparison of Phases 1 & 2

The table below provides a comparison of the projected emissions for Phase 1 and Phase 2 (in $ktCO_2e$) and by scenario.

Table 10-9: Emission projections for the NETs sector under the baseline and under modelled scenarios, for both Phase 1 and Phase 2 (in $ktCO_2e$)

Phase	Scenario	Emissions ($ktCO_2e$)						
		2019	2020	2025	2030	2035	2040	2045
n/a	**Baseline**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
1	**Central Growth**	**0**	**0**	**0**	**0**	**-2,443**	**-5,700**	**-5,700**
	High Growth	0	0	0	0	-2,931	-6,840	-6,840
	Low Growth	0	0	0	0	-2,443	-5,700	-5,700
	High Hydrogen	0	0	0	0	-2,443	-5,700	-5,700
	Low Hydrogen	0	0	0	0	-1,954	-4,560	-4,560
2	**Central Growth**	**0**	**0**	**0**	**0**	**-2,443**	**-5,700**	**-5,700**
	High Growth	0	0	0	0	-2,931	-6,840	-6,840
	Low Growth	0	0	0	0	-2,443	-5,700	-5,700
	High Hydrogen	0	0	0	0	-2,443	-5,700	-5,700
	Low Hydrogen	0	0	0	0	-1,954	-4,560	-4,560

10.3.4 Emissions reduction by policy package (2032) – Phase 1 & 2

Only one policy package was modelled for the NETs sector and, as impacts are only seen in later years, there are no emissions reductions associated with this package in 2032.

10.4 Uncertainties

The calculations for BECCS and DAC are based on one type of plant alone for each. For BECCS, there are several different end applications, all of which can use a variation of biomass feedstocks, conversation technologies and CO_2 capture technologies. Hence depending on the type of BECCS plant operating, final figures for emissions captured and electricity usage will vary, resulting in uncertainties in the modelled figures. The calculation for electricity consumption per tCO_2 captured is also based off of one large plant. In reality, it is likely that this would be through multiple, smaller plants, and hence creates additional uncertainty in the modelled figures. Implementation of BECCS in different applications will also result in variances in the inputs and hence result in further differences to the modelled emissions.

For DAC, there are several different CO_2 capture technologies, such as liquid solvent and solid adsorbent. The calculations for electricity consumption are only based on one technology, and hence this will also lead to uncertainties in the modelled figures.

As most NETs are still not commercially mature, the future landscape for implementation will likely depend on several factors which are not considered within the model. The current targets for BECCS and DAC, as outlined in Section 10.2.1, may shift depending on factors such as views on the sustainability of biomass and use of biomass imports, as well as the importance of BECCS by-products such as heat, power and hydrogen. The use of biochar for greenhouse gas removals is also gaining increasing importance, hence this is a further sensitivity to this analysis since biochar is not considered within the model.

10.5 Sensitivities

Emissions projections for NETs would normally be sensitive to the carbon intensity of the grid, but as the emissions from electricity generation are modelled under the Electricity sector, this is not visible in these results.

11. Land Use, Land-Use Change and Forestry (LULUCF) sector

The work on this sector was completed by UK CEH.

The unique and biologically complex characteristics of this sector meant that a sector specific model was used to generate the projections. The methodological approach to the work was very different to that taken in the other sectors of the work. Details of the work are provided in Appendix 1. The complexity of the LULUCF sector also contributes to relatively high uncertainty in the net emissions from this sector, as all sources and sinks are based on computer models rather than direct measurement. It is a very active area of scientific development, with annual methodological improvements. As the sector is a combination of sources and sinks, a change in one activity can have a relatively large impact on the net sectoral emissions.

The main focus of emission projections in this sector were afforestation and peatland restoration. Net emissions from afforestation were estimated using the Woodland Carbon Code Calculator (see Appendix 1, section 8.1), calibrated to match results from the CARBINE model used for the national greenhouse gas inventory (this model is proprietary to Forest Research and was not available for this project).

Net emissions from peatland restoration were calculated using the same peatland condition base-map and emission factors used in the national GHG inventory (see Appendix 1, section 8.2). Three abatement scenarios were modelled:

- Low - restoration focused in the uplands (i.e. Modified Bog and Extensive Grassland), and an average (2018-2020) restoration rate to 2030;
- Central - restoration focussed in the uplands (i.e. Modified Bog and Extensive Grassland) to reach 591 kha of restoration by 2045;
- High - restoration targeted at higher-emitting land categories (40% reduction in Extraction, Cropland and Intensive Grassland), and the remaining split across the upland categories, to reach 591 kha of restoration overall by 2045.

The Low, Central and High peatland restoration scenarios results in estimated emissions reductions of 0.2 , 2.0, and 2.9 MT CO_2e, respectively, by 2045. In the High scenario, the reduction of operational peat extraction provides additional emissions saving of 0.1 Mt CO_2e from a reduction in carbon lost by oxidation of the harvested peat. The emissions reductions from the Central and High scenarios are substantial and demonstrate that targeted restoration in the lowlands can result in additional emissions reductions; however, the feasibility of this scenario is unclear due to the large uncertainty in the estimates of the land areas involved.

In the overall SG Projections model, an offset of -4073.866 kt CO_2e is applied to output of the LULUCF modelling work from 2021 onwards to remove a large time series inconsistency in emissions. This inconsistency arises from the use of different methods/models for the calculation of organic soil emissions under Forestry: a Tier 2 approach (using a time-independent emission factor) rather than the CARBINE process-based model used in the UK GHGI, which implies a variable emission factor over time (See Appendix 1, section 8.3). The offset provides a smooth emissions trajectory that allows a partial comparison with the Scottish Sector Emissions Envelope for LULUCF. This offset was applied by the Ricardo modelling team.

12. Final modelling outcome

Phase 1 (CCPu Policy Impacts)

Figure 12-1shows total GHG emissions and sectoral contributions throughout the projection period for the central scenario of the Phase 1 modelling. Table 12-1Table 1-1 shows the results of the Phase 1 modelling (i.e., of policies assessed during the study) for the central scenario (including the LULUCF sector) for key years. Note that 2032 is included as a key year as this is the end-year for the CCPu.

Figure 12-1: Total emissions (kt CO_2e) split by sector for the central scenario of the Phase 1 modelling.

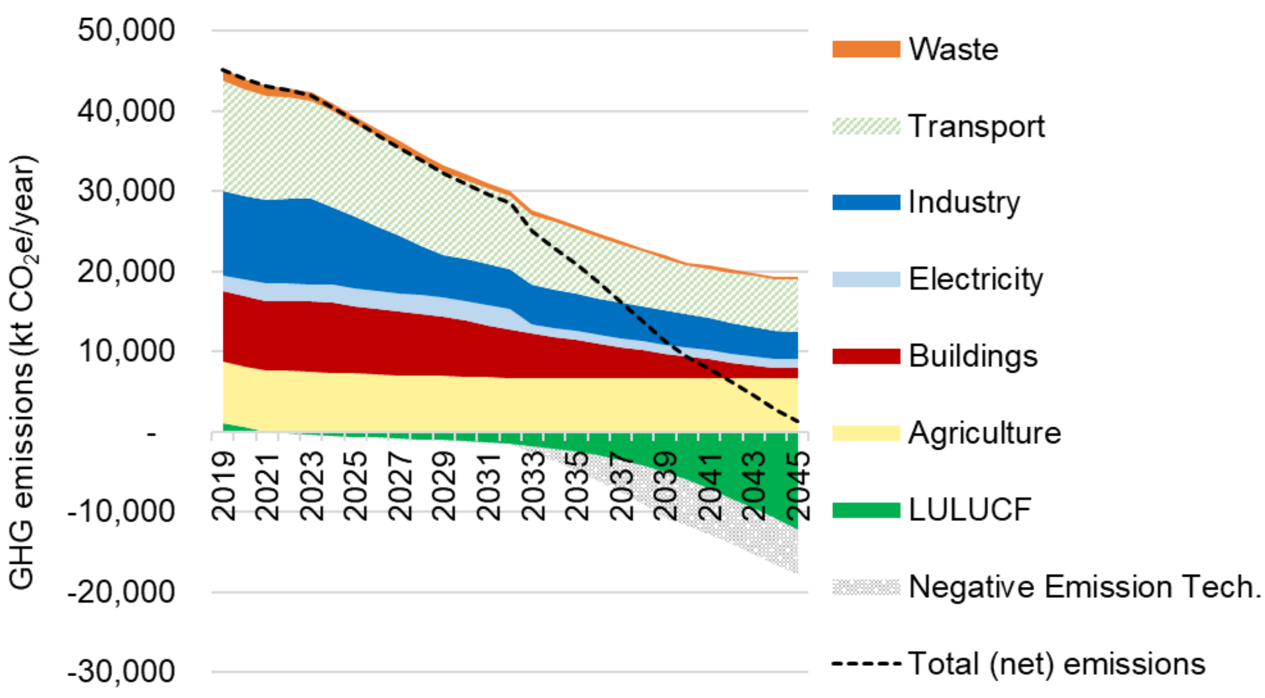


Table 12-1. Emissions reductions for the central scenario (including LULUCF) under the Phase 1 modelling

	2025	2030	2032	2035	2040	2045	2050
Emissions reduction from baseline (kt CO_2e)	5,763	13,887	16,781	24,981	37,371	46,224	52,923
Percentage reduction from baseline	13%	31%	37%	55%	80%	97%	111%

Key take-home points from this analysis are summarised below:

- The biggest emissions reductions are from the Buildings and Transport sectors. Emissions reductions in these sectors are primarily associated with the phase-down of fossil fuel use in favour of electrically powered technologies or other zero emission alternatives. In both cases, this type of “fuel switching” has a larger GHG emissions impact than measures aimed at energy demand reduction such as increasing sustainable travel modes or retrofitting buildings. However, such measures should still be seen as important as they help to minimise demands on grid infrastructure, avoid indirect emissions from vehicle manufacture, reduce people's energy bills, and so on.

- Industrial sector decarbonisation is assumed to proceed in line with the requirements of the UK Emissions Trading Scheme (ETS). This is the key policy driving GHG reductions in the industrial sector; the majority of the other CCPu proposals were considered not to have a quantifiable impact on emissions although they would act as supporting measures that could facilitate decarbonisation.
- The results show "negative emissions" from the LULUCF sector, as peatland restoration and afforestation would increasingly act as a carbon sink, along with NETs. However, in both cases the results should be interpreted with great caution.[61] The complexity of the LULUCF sector contributes to relatively high uncertainty in the net emissions from this sector, as all sources and sinks are based on computer models rather than direct measurement. The central scenario modelled for LULUCF is based on ambitious peatland restoration rates, but the feasibility of this scenario is unclear. In the case of NETs, we have modelled the sector reaching the quantitative targets set out in the CCPu. However, the sector is in its infancy and the specific proposals in the CCPu would not necessarily guarantee this level of deployment. If one excludes the LULUCF and NETs from the analysis, GHG emissions in 2045 would be close to 20 $MtCO_2e$.
- The Agriculture sector shows a relatively small reduction in emissions which, in this analysis, is driven by the Agricultural Transformation Programme. Most of the other policies relating to the Agriculture sector do not have quantifiable GHG emissions impacts, either because they are considered supporting measures or due to lack of data.
- For the Waste sector, reducing the amount of biodegradable waste sent to landfill is considered the main driver of GHG emissions reductions. The target of reducing food waste would contribute towards further reductions. Waste is a complicated sector and there were some measures, such as the aim of establishing a more circular economy, which hold the potential to reduce net emissions globally but where it was not possible to provide a quantitative, sector-based estimate within the scope of this project.
- Electrification, which is key to reducing emissions from the Buildings, Transport and Industry sectors in particular, will rely on access to a secure, reliable source of renewable electricity. The Electricity sector policies in the CCPu can therefore be said to reduce emissions from multiple sectors indirectly, inasmuch as they

[61] The LULUCF sector was modelled using a sector specific model that required a large offset to be applied to its output from 2021 onwards to remove an inconsistency between its output and the historical time series data obtained from the 2022 Devolved Administration Inventory. Although theoretically, the output from this work including LULUCF suggests net zero could be achieved by 2050, caution is advised due to the adjustments made to integrate the LULUCF sector into our work. To achieve a higher degree of accuracy and lower uncertainty in the LULUCF sector projections, Scottish Government would need to use the CARBINE model to re-model projections in this sector. This was not possible within the time-frame and resources of this work.

minimise the need to generate electricity using unabated fossil fuels. The largest impacts in this sector that have been assessed in this study are associated with (a) to the Peterhead gas power station being decommissioned and replaced with a carbon capture, storage and utilisation (CCS) gas power station and (b) additional offshore wind capacity.

The results of this analysis show Scotland coming very close to its net zero target by 2045 and achieving net negative emissions by 2050. However, bearing in mind the uncertainty around the LULUCF estimates and deployment of NETs in particular, **there is a very high risk that the Scottish Government's statutory targets will not be achieved through reliance on action covered by Phase 1 and without additional policies**. As shown above, without the GHG reductions from the LULUCF and NETs, there could be a gap of close to 20 $MtCO_2e$ by 2045 between actual emissions and the target level without additional policies. That may still be an optimistic assessment given the lack of a defined regulatory approach for some important mitigation measures, such as phasing out fossil fuel heating in buildings.

The sensitivity of results to the different growth scenarios is discussed below, with the Phase 2 results.

Phase 2 (CCPu Outcome Impacts)

Figure 12-2 shows total GHG emissions and sectoral contributions throughout the projection period for the central scenario of the Phase 1 modelling. Table 12-2 shows the results of the Phase 2 modelling (i.e., of policies) for the central scenario (including the LULUCF sector) for key years.

Figure 12-2: Total emissions (kt CO_2e) split by sector for the central scenario of the Phase 2 modelling.

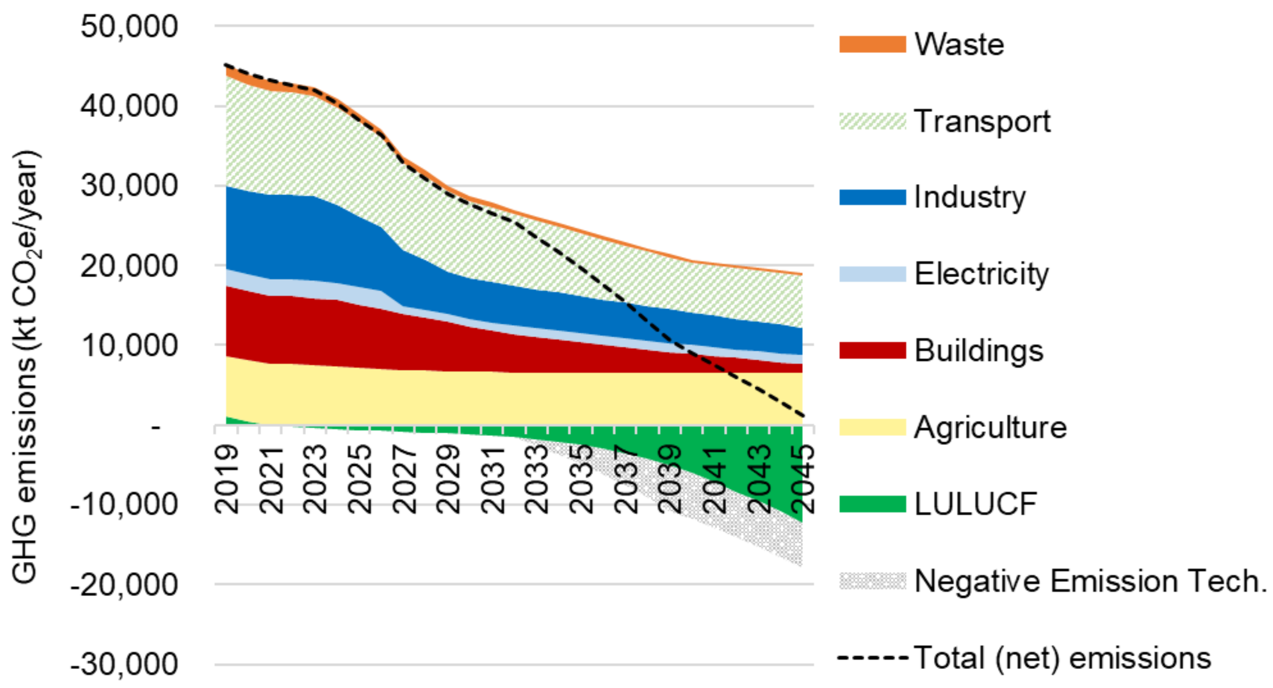


Table 12-2. Emissions reductions for the central scenario (including LULUCF) under the Phase 2 modelling

	2025	2030	2032	2035	2040	2045	2050
Emissions reduction from baseline (kt CO_2e)	6,176	17,146	19,767	26,122	37,781	46,397	53,096
Percentage reduction from baseline	14%	38%	44%	57%	81%	98%	111%

As with Phase 1, all sectors see reductions in GHG emissions to 2045, but residual emissions remain in all sectors (apart from LULUCF and NETs). The LULUCF and NETs sectors are expected to help mitigate these residual emissions, but again it is very important to note the high uncertainty associated with both the scale of reductions that can be achieved, and the likelihood/timing of delivery.

The difference in Phase 2 is due to small additional GHG reductions occurring in the Agriculture, Buildings and Transport sectors:

- In Agriculture the difference is due to updates in the modelling methodology rather than a difference in the overall level of ambition.
- In Buildings the difference is due to changes in the targets that were modelled for non-domestic buildings; in Phase 1 this was based on decarbonising a certain number of buildings whereas in Phase 2 the targets related to overall fossil fuel consumption.
- In Transport the difference is primarily due to greater reductions in private vehicle use.

No further reductions in Phase 2 are seen in the NETs, Industry, and Waste sectors as no further impacts were modelled in these sectors – this is because no further quantifiable targets were identified through discussions with Scottish Government in these sectors at the time of writing. In some cases, there was a change in the cumulative emissions for certain sectors, for example due to changes in the timing of measures. For example, for the Electricity sector, 2045 emissions are the same between Phase 1 and Phase 2, but Phase 2 sees emissions reduce to their final level much earlier due to the change in presumed timing of CCS at Peterhead. The most significant emissions reductions from the baseline in 2045 are seen in the Industry sector (-8,187 ktCO_2e under the central scenario in 2045), the Buildings sector (-8,217 ktCO_2e under the central scenario in 2,045), and the transport sector (-7,491 ktCO_2e under the central scenario in 2045). NETs also contribute significantly, accounting for -5,700 ktCO_2e of emissions reductions under the Central scenario in 2045. Smaller contributions are made by the Electricity sector (-1,462 ktCO_2e under the central scenario in 2045), the Agriculture sector (-1,007 ktCO_2e under the central scenario in 2045) and the Waste sector (-493 ktCO_2e under the central scenario in 2045).

The most important take-home points of the Phase 2 analysis are similar to those described for Phase 1 (see above). The Phase 2 modelling also highlights the potential to achieve lower cumulative emissions though adoption of stronger policy ambition and/or bringing forward key policy interventions.

Comparison between scenarios

The graphs below present a time-series of emissions under all modelled scenarios, for both Phase 1 (Figure 12-3) and Phase 2 (Figure 12-4) of the modelling.

Figure 12-3. Emissions projections under all modelled scenarios, for Phase 1.

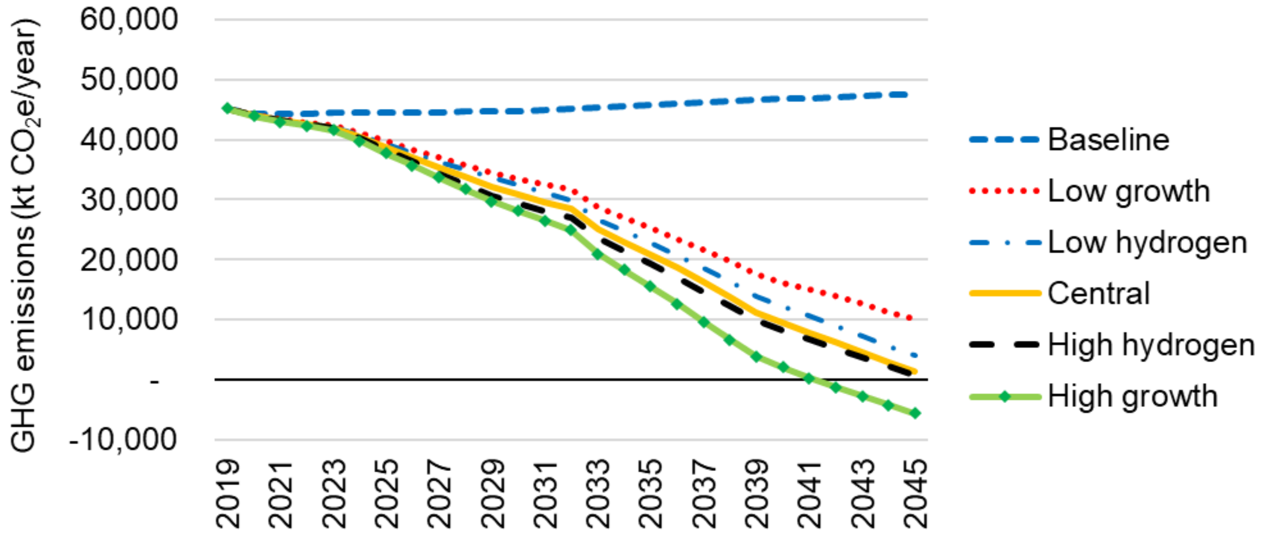
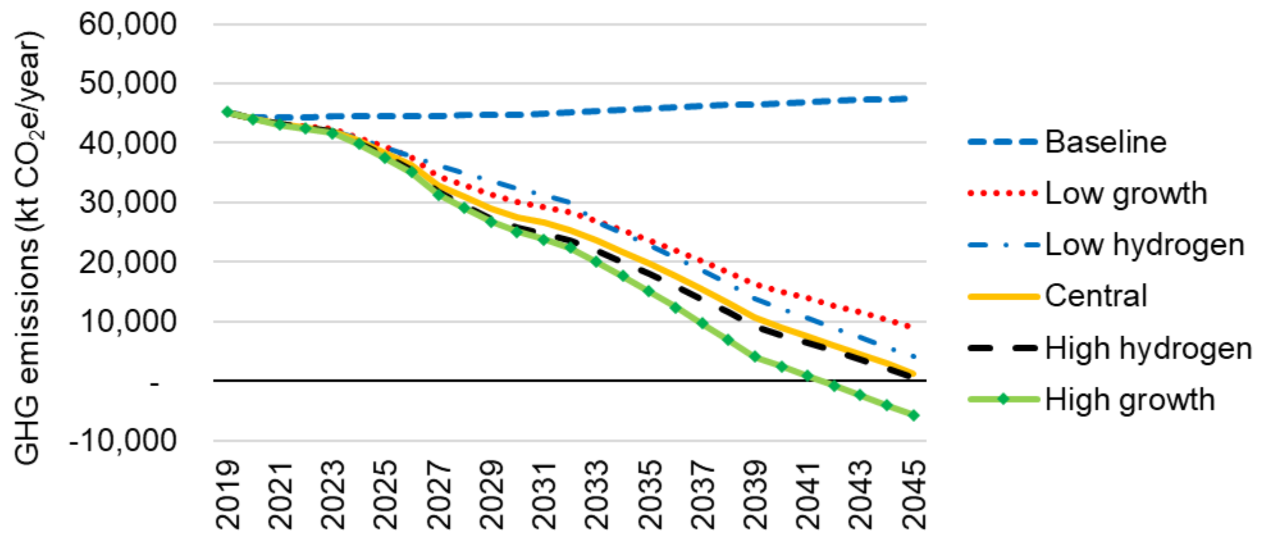


Figure 12-4. Emissions projections under all modelled scenarios, for Phase 2.



While the differences in results between the different growth scenarios appear limited, they are nonetheless materially important. Under Phase 2, the high growth scenario delivers reductions of 53,346 ktCO$_2$e, while the low scenario delivers reductions of 38,689 ktCO$_2$e – the high growth scenario therefore delivers reductions 38% higher than the low growth scenario.

Hydrogen scenarios were only modelled for Buildings, Industry and NETs, as these were the only sectors where future hydrogen availability was considered likely to have a significant material impact on sector development and sectoral emissions. The differences between emissions projections under the growth scenarios and under the hydrogen scenarios are extremely small. The most important finding here, is that emissions projections are more sensitive to growth scenarios than to hydrogen scenarios (i.e., the difference between growth scenario results is greater than between hydrogen scenario results), meaning that future economic growth can be expected to have a greater bearing on Scotland's future GHG emissions than the future availability of (green) hydrogen.

APPENDICES

Appendix 1 contains the full details of the LULUCF sector modelling work.

Appendix 2 contains information on historical GHG emissions in Scotland.

Appendix 3 contains the detailed methodology for the Buildings sector.

Appendix 1. Land Use, Land-Use and Foresty (LULUCF)

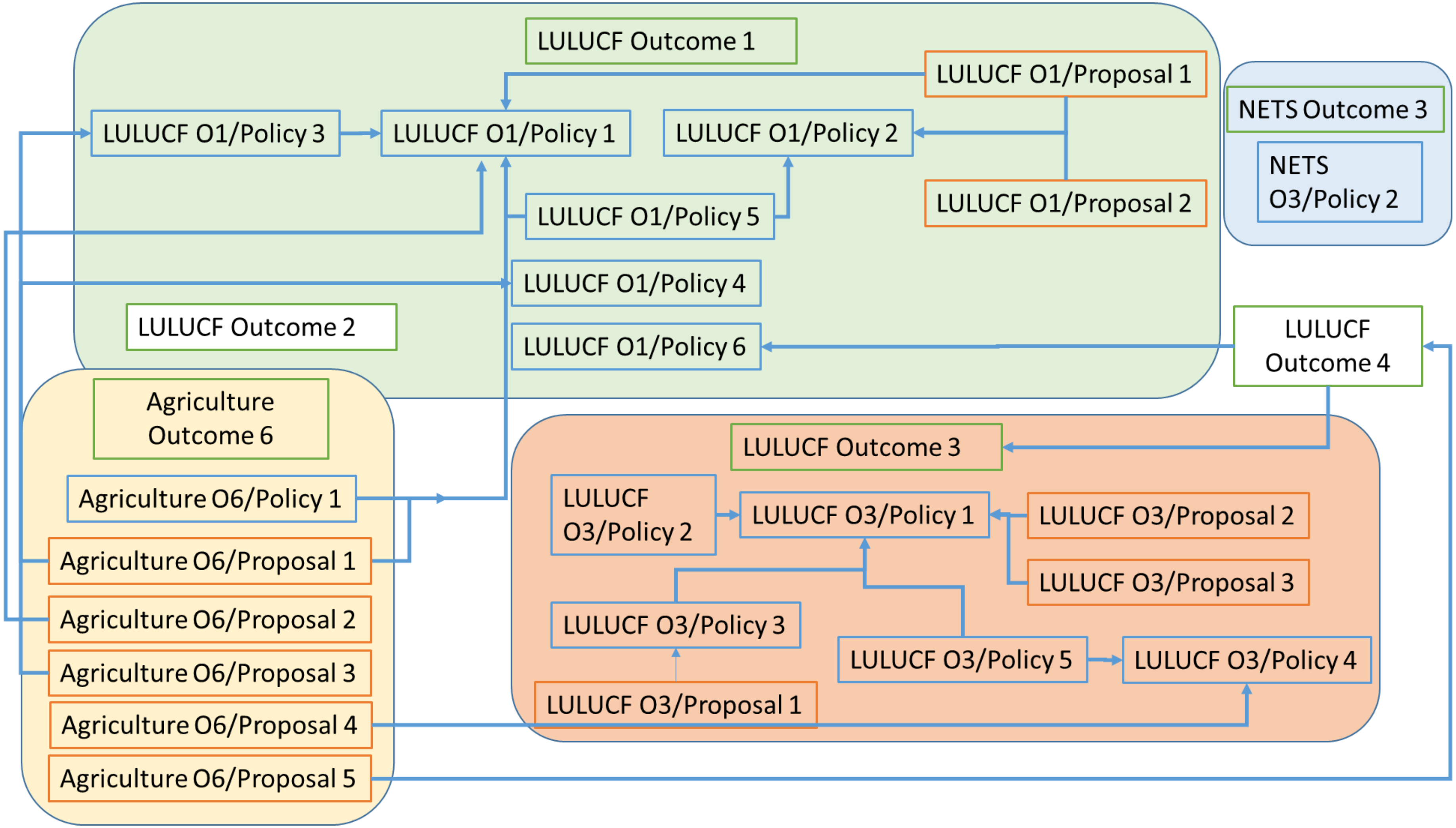
Scottish Government Projections: LULUCF sector

Authors: Amanda Thomson, Hannah Clilverd, Gwen Buys

Date: 21st November 2022

UKCEH have assessed six Outcomes, underpinned by 13 policies and 10 proposals in the LULUCF, Agriculture and Negative Emissions Technologies sectors. The majority of these are related to forestry/woodland and peat restoration activities. UKCEH have produced quantified emission projection scenarios where possible, and discuss if quantification of projected emissions is possible in other cases. There are linkages between many of the policies and proposals, as shown in Figure 12-5.

Figure 12-5: Linkages between LULUCF and other land-based policies/proposals



12.1 LULUCF Outcome 1: We will introduce a stepped increase in the annual woodland creation rates from 2020-2021 to enhance the contribution that trees make to reducing emissions through sequestering carbon.

The Climate Change Plan Update (CCPU 2018-2032) has targets for annual woodland creation for 2020/21 to 2024/25, stepping up to a maximum of 18,000 ha p.a. The Climate Change Plan Monitoring Reports 2022 Compendium (CCPu Monitoring Compendium) indicator for this outcome is that levels of woodland creation are on-track. These planting targets are reflected in the assumptions underpinning the LULUCF Central Scenario GHG emission projections for the 1990-2019 inventory (submitted to BEIS but not yet published). Annual woodland creation rates return to a very low level (326 ha p.a.) from 2025/26 onwards. The GHG emissions from forestry in the LULUCF Central Scenario projections are modelled using the Forest Research CARBINE model. CARBINE is a carbon accounting model that calculates gains and losses in pools of carbon in standing trees, litter and soil in conifer and broadleaf forests. It represents UK forestry systems as a combination of tree species composition, tree growth rate (yield class) and management regime. Information on forestry systems comes from the Sub-compartment Database of publicly owned and managed woodlands, and the National Forest Inventory survey of woodlands for privately owned woodlands.

The CCPU 2018-2032 (page 19) also has a target of 21% of Scottish land area covered by forest by 2032. This would not be achieved by the current woodland creation targets to 2024/25, which would increase woodland cover from 18.8% in 2021 to 19.8% by 2025. In order to achieve the 21% target, a woodland creation rate of 18,000 ha p.a. would have to be maintained between 2025/26 and 2030/31. The planting rates used in this modelling for Policy 1 and Policy 2 are shown in Table 1.

Table 12-3: Modelled planting rates for Policy 1 (private) and Policy 2 (public).

Year	Annual planting rate, ha				
	Sector Split		Tree Type Split		Total planting
	Public planting	Private planting	Broadleaf planting	Conifer planting	
2019	1,030	10,190	4,037	7,173	11,220
2020	270	10,780	3,803	7,247	11,050
2021	570	10,090	3,803	6,857	10,660
2022	782	13,843	5,224	9,401	14,625
2023	862	15,263	5,760	10,365	16,125
2024	942	16,683	6,296	11,329	17,625
2025-2030	962	17,038	6,430	11,570	18,000
2031-2045	17	309	116	210	326

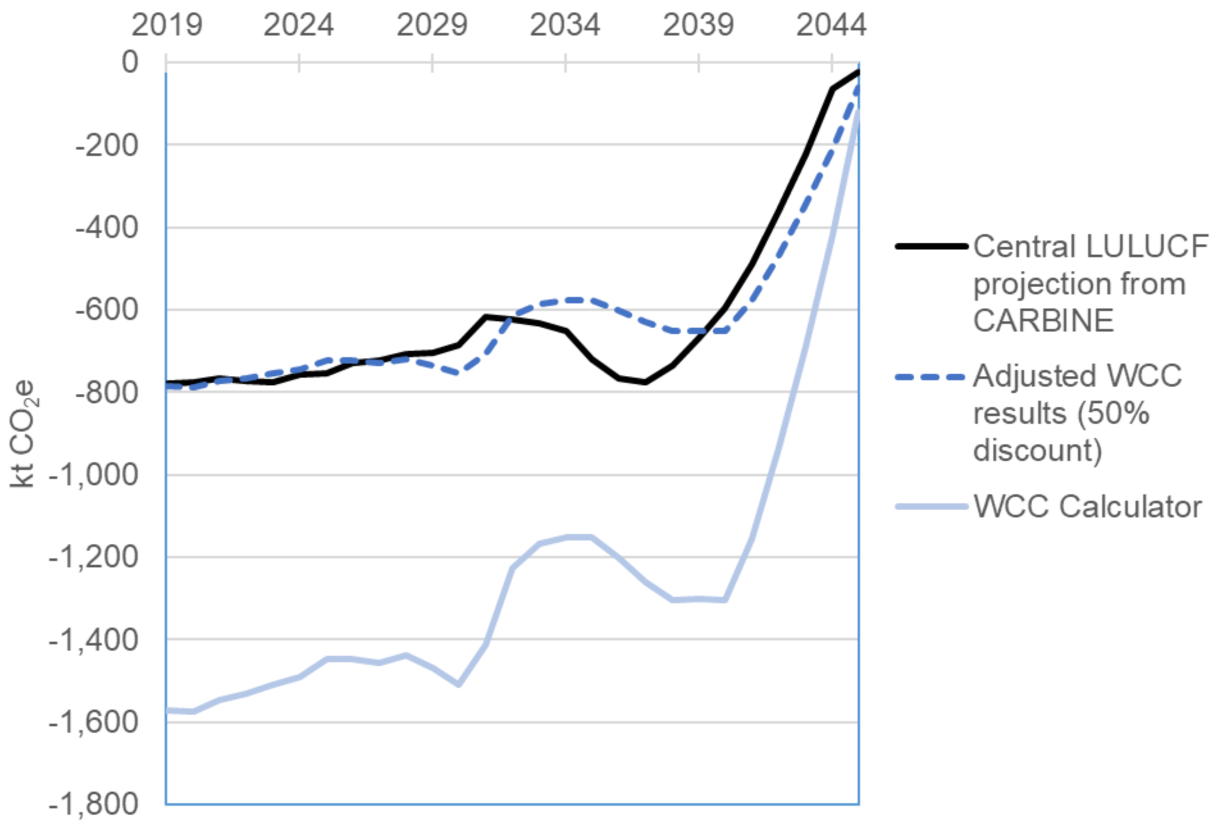
We used the Woodland Carbon Code (WCC) Calculator (version 2.4 March 2021) to estimate the impact on net carbon emissions and removals of these increased woodland creation rates on Forestry and Land Scotland (FLS) land (public planting) and private land (assumed all funded by the Forestry Grant Scheme). The WCC Calculator takes account of cumulative carbon sequestration in living biomass and debris, emissions from woodland establishment and emissions from ongoing management. It is based on the same underlying yield tables as CARBINE, but cannot represent the same level of management detail. There are yield tables for the most commonly planted species in the UK, listed by yield class (YC). Forest Research define YC as “an index used in Britain of the potential productivity of even-aged stands of trees. It is based on the maximum mean annual increment of cumulative timber volume achieved by a given tree species growing on a given site and managed according to a standard management prescription.”

The WCC Calculator results were compared with the LULUCF Central Projection results for biomass carbon stock change for the Land converted to Forest GHG Inventory category, i.e. the sum of all annual biomass stock change from areas of woodland creation in the 20 years preceding the year of reporting (e.g. 2019: woodland creation 1999-2019). We used the same areas of broadleaf and conifer planting, assuming species/yield/management classes of:

- Broadleaf: Sycamore/Ash/Birch YC 6, 2.5m spacing, no thinning
- Conifer: Sitka Spruce YC16, 2.0m spacing, thinning management

These species are the most commonly planted in Scotland and the assumptions match those used in the quantitative analysis used for the Committee on Climate Change 6th Carbon Budget report (Thomson et al. 2021). An assumption of 15% open space was included in the area planted and the results include the 20% discount for WCC model precision but not the 20% contribution to the buffer for carbon issuance units. The comparison is shown in Figure 12-6. The WCC Calculator results exhibit the same trend over time as the Central projection from CARBINE, but carbon sequestration estimates are much larger. In discussion with Forest Research experts this difference is due to several factors: CARBINE includes a much wider range of species, yield classes and management regimes in historic and projected planting, and also incorporates mortality and decomposition in its calculations. The WCC Calculator results were calibrated to the CARBINE output using a 50% discount, giving a much closer match. Any future work in this area should ideally make use of the CARBINE model directly.

Figure 12-6: Comparison of biomass carbon stock change for the Land converted to Forest 20-year transition GHG Inventory category between results from the WCC Calculator and the LULUCF Central projection from CARBINE



We included emissions from soil disturbance from seedling establishment in the WCC Calculator (-0.38 tCO_2e/ha based on 2.0m seedling spacing) but did not include other emissions from establishment such as fuel used in ground preparation, tree shelters, fencing, herbicide, road building or removal of other vegetation from the site. Neither did we include the soil carbon emission calculation of the WCC: for soils on pasture or semi-natural grassland. The WCC Calculator assumes soil carbon emissions are zero for negligible or low disturbance planting but 2% (11.7 t CO_2e/ha) of soil carbon is lost with medium disturbance on mineral soils and 10% (58.7 t CO_2e/ha) with organomineral soils (higher disturbance planting approaches have even higher losses). Project resources did not allow for an in-depth assessment of the distribution of planting on different soil types or with different planting approaches. Only planting on mineral soils previously in arable use allows for soil carbon accumulation in the WCC Calculator, and this is insignificant in Scotland.

The estimated net emission factors for soil carbon (losses and accumulation) in the national GHG Inventory for woodland establishment on grassland are 3.2 t CO_2e/ha/yr for broadleaf and 2.6 t CO_2e/ha/yr for conifer for planting <20 years old (losses to the atmosphere), and -0.5 t CO_2e/ha/yr for broadleaf and -1.8 t CO_2e/ha/yr for conifer from older woodlands. These are broadly comparable overall with the WCC rates for medium disturbance on mineral soils.

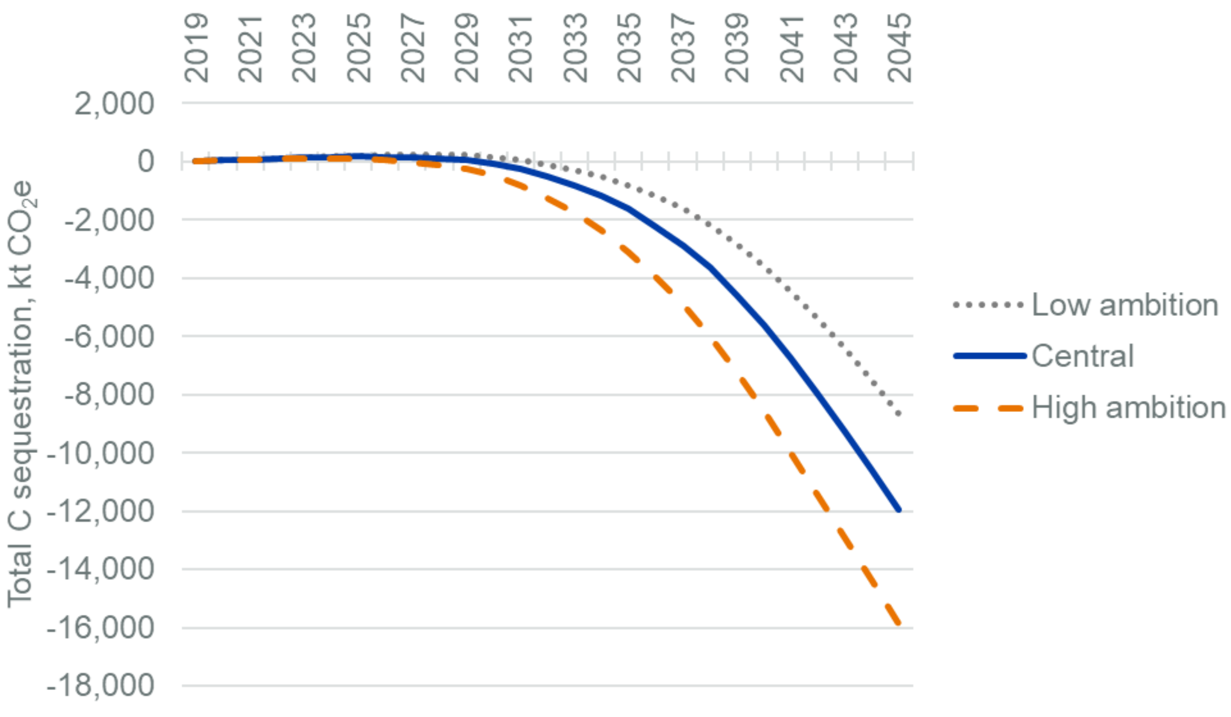
Net carbon emissions from woodland creation on public and private land were calculated separately and combined for the total from this Outcome (Figure 12-7). Biomass net carbon sequestration was estimated using the WCC Calculator and adjusted using a 50%

discount, and net soil carbon emissions were calculated using the estimated emission factors from the LULUCF inventory (Figure 12-8). High and low growth scenarios were produced by changing the species-yield class assumptions rather than the area planted.

The estimated total net carbon sequestration from woodland creation by 2045 in the Central scenario is -11.9 Mt CO_2e (-15.9 Mt CO_2e in the High growth scenario, and -8.6 Mt CO_2e in the Low growth scenario).

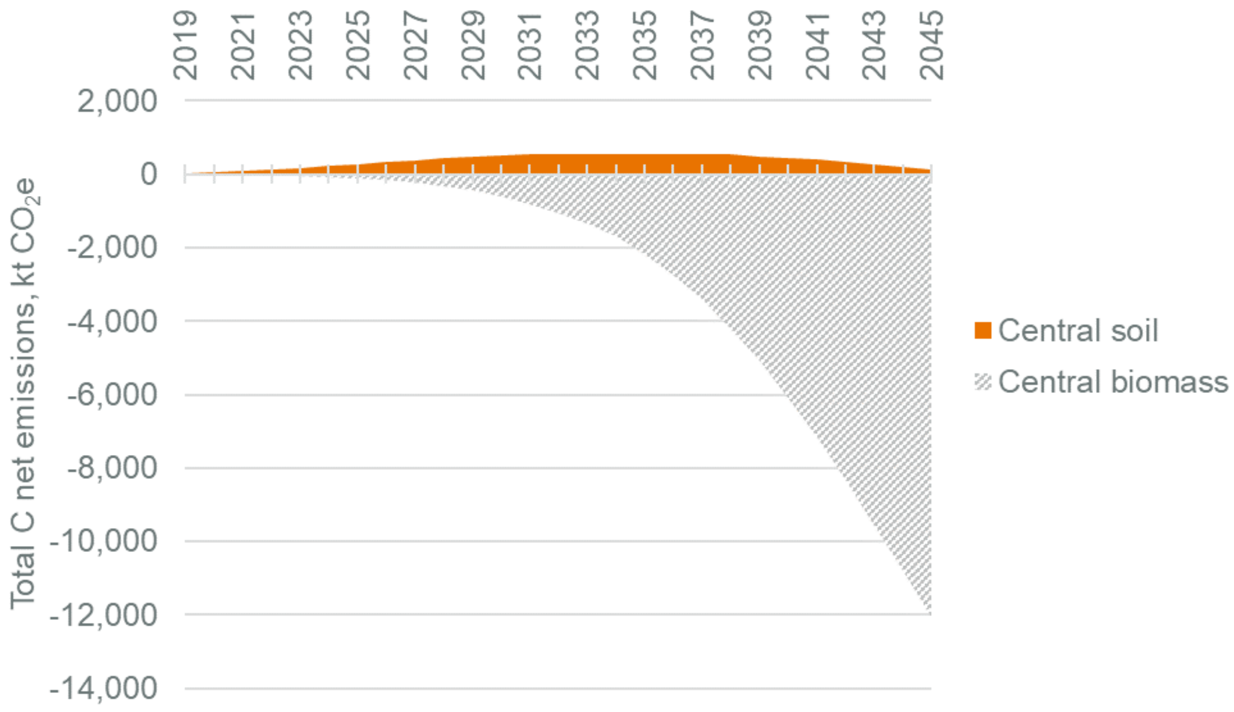
Caveats: These greenhouse gas emission estimates will likely be superseded by a new report on forestry and climate change modelling by Forest Research, FLS etc., with a summary report published in July 2022[62]. This report gives annualised rates of carbon sequestration under different management options and different time periods, and it has not been possible to directly compare detailed results. At a high level, the estimated annualised carbon sequestration rates for planting 2019-2045 (12.5, 19.5 and 7.7 tCO_2/yr for the Central, High and Low scenario) lie within the range of 0 tCO_2/yr for lightly managed broadleaves and 16.0-56.1 tCO_2/yr for moderate/fast growing thinned conifers for planting 2022-2025.

Figure 12-7: Total net carbon sequestration from woodland creation on all land



[62] Forest Research, *'Quantifying the sustainable forestry cycle – Summary Report'* (2022). Available at: https://cdn.forestresearch.gov.uk/2022/07/QFORC_Summary_Report_rv1e_final.pdf

Figure 12-8: Net emissions from biomass and soil for the Central scenario



12.1.1 Policy 1: Forestry grants: we will provide funding via a grant scheme, to support eligible land owners establish appropriate woodlands –Full assessment

It was assumed that 95% of the woodland created under the annual targets would be on private land, based on the percentage in 2021, and funded by the Woodland Creation component of the Scottish Forestry Grant Scheme (SFGS). There are 10 planting options under this scheme and a woodland species class was assigned to each planting option. The assumptions on woodland species class were based on Scottish woodland composition from the National Forest Inventory, information in the SFGS criteria and assumed yield classes in the CCC Balanced Pathway scenario and BEIS GGR scenario modelling (Table 12-4). The area of woodland created did not change between the Central, High and Low scenarios, but the species YC assumptions did change. The proportion of each option was estimated from the mean claimed areas of each option in the January 2022 SFGS Statistics and kept constant over time.

Although Agroforestry is one of the SFGS options, the SFGS statistics do not record any claimed areas in the past five years. Other SFGS schemes are for harvesting and processing, woodland improvement and sustainable management do not contribute to the woodland creation targets.

Table 12-4a: Forestry grant planting assumptions (species, yield class, management, spacing)

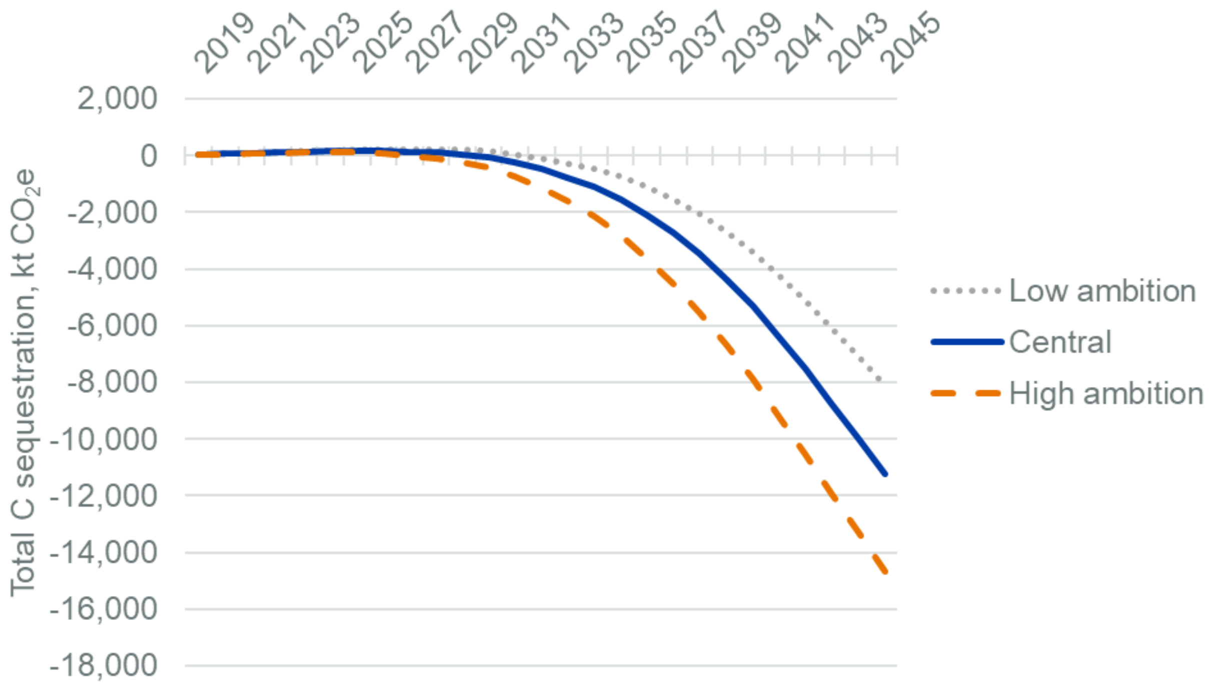
	Species/yield class/Management assumption			
SFGS Option	**Central scenario**	**High growth scenario**	**Low growth scenario**	**% 2017-2021**
Conifer	Sitka spruce, YC16, Thinned, 2.0m spacing	Sitka spruce, YC20, Thinned, 2.0m spacing	Sitka spruce, YC14, Thinned, 2.0m spacing	51.2%
Diverse conifer	Norway spruce, YC16, Thinned, 1.5m spacing	Norway spruce, YC20, Thinned, 1.5m spacing	Norway spruce, YC14, Thinned, 1.5m spacing	7.0%
Broadleaves	Beech, YC8, Thinned, 2.5m spacing	Beech, YC10, Thinned, 2.5m spacing	Beech, YC6, Thinned, 2.5m spacing	4.0%
Native Broadleaves	Sycamore/Ash/Birch, YC8, No-thinning, 2.5m spacing	Sycamore/Ash/Birch, YC10, No-thinning, 2.5m spacing	Sycamore/Ash/Birch, YC6, No-thinning, 2.5m spacing	14.1%
Native Scots Pine	Scots Pine, YC10, No-thinning, 2.0m spacing	Scots Pine, YC14, No-thinning, 2.0m spacing	Scots Pine, YC8, No-thinning, 2.0m spacing	7.4%
Native Upland Birch	Sycamore/Ash/Birch, YC6, No-thinning, 2.5m spacing	Sycamore/Ash/Birch, YC8, No-thinning, 2.5m spacing	Sycamore/Ash/Birch, YC4, No-thinning, 2.5m spacing	9.7%
Small or Farm Woodland	Sycamore/Ash/Birch, YC8, No-thinning, 2.5m spacing	Sycamore/Ash/Birch, YC10, No-thinning, 2.5m spacing	Sycamore/Ash/Birch, YC6, No-thinning, 2.5m spacing	1.0%
Native broadleaves in Northern and Western Isles	Sycamore/Ash/Birch, YC6, No-thinning, 2.5m spacing	Sycamore/Ash/Birch, YC8, No-thinning, 2.5m spacing	Sycamore/Ash/Birch, YC4, No-thinning, 2.5m spacing	0.1%

Table 12-5b: Forestry grant planting assumptions (species, yield class, management, spacing) - continued

	Species/yield class/Management assumption			
SFGS Option	**Central scenario**	**High growth scenario**	**Low growth scenario**	**% 2017-2021**
Native Low Density	80% Natural Regeneration-Mixed Broadleaf, YC4, No-thinning, 3.0m spacing 20% Natural Regeneration- Scots Pine, YC4, No-thinning, 2.0m spacing	80% Natural Regeneration-Mixed Broadleaf, YC4, No-thinning, 3.0m spacing 20% Natural Regeneration- Scots Pine, YC4, No-thinning, 2.0m spacing	80% Natural Regeneration-Mixed Broadleaf YC2, No-thinning, 3.0m spacing 20% Natural Regeneration- Scots Pine, YC2, No-thinning, 2.0m spacing	1.1%
Natural regeneration	80% Natural Regeneration-Mixed Broadleaf, YC4, No-thinning, 3.0m spacing 20% Natural Regeneration- Scots Pine, YC4, No-thinning, 2.0m spacing	80% Natural Regeneration-Mixed Broadleaf, YC4, No-thinning, 3.0m spacing 20% Natural Regeneration- Scots Pine, YC4, No-thinning, 2.0m spacing	80% Natural Regeneration-Mixed Broadleaf, YC2, No-thinning, 3.0m spacing 20% Natural Regeneration- Scots Pine, YC2, No-thinning, 2.0m spacing	4.4%

The estimated total net carbon sequestration from woodland creation by 2045 in the Central scenario is -11.2 Mt CO_2e (-14.7 Mt CO_2e in the High growth scenario, and -8.1 Mt CO_2e in the Low growth scenario) (Figure 12-9).

Figure 12-9: Total net carbon sequestration from woodland creation from forestry grants



12.1.2 Policy 2: Woodland creation on Scotland's national forests and land. Forestry and Land Scotland will deliver an annual contribution towards the overall woodland creation target by creating new sustainable woodland on Scotland's national forests and land, including through partnerships with external organisations to scale carbon capture opportunities. – Full assessment

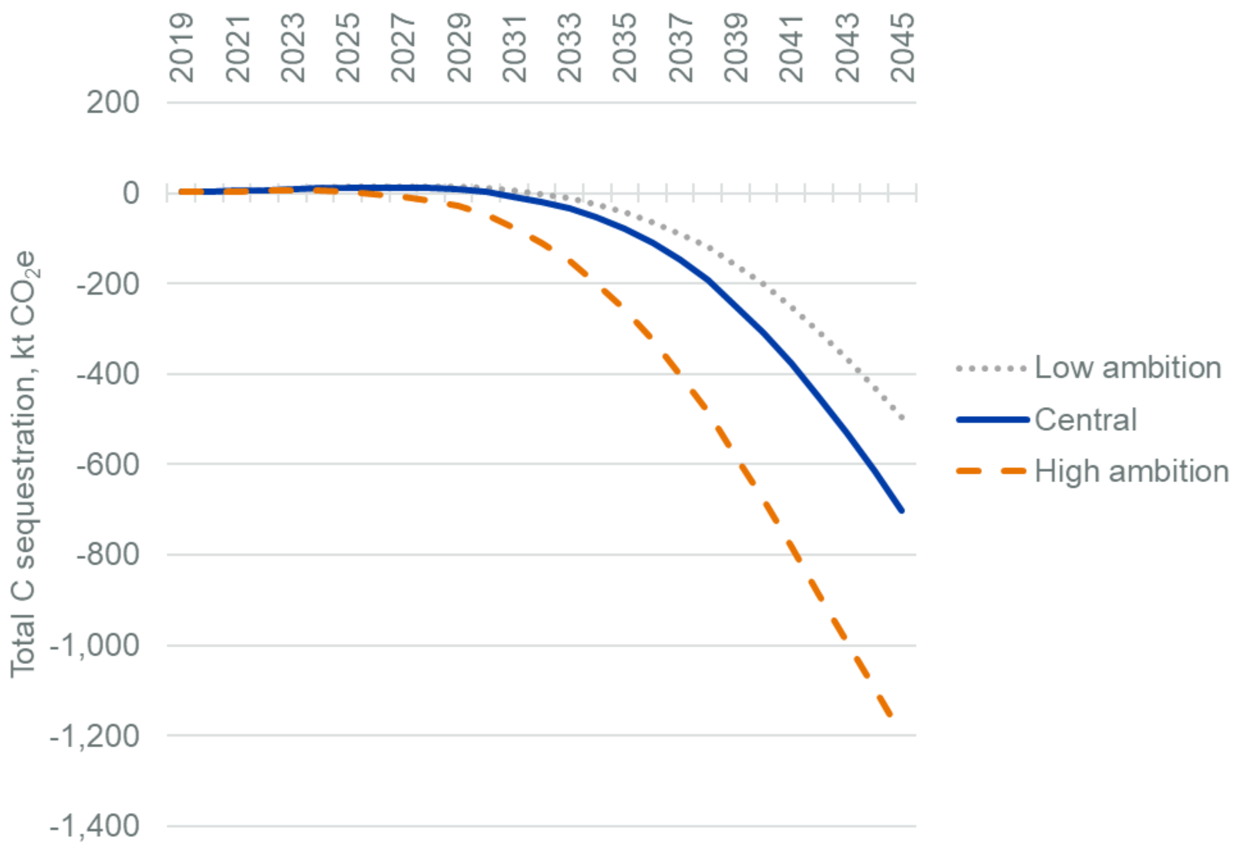
It was assumed that 5% of the woodland created under the annual targets would be on Scotland's national forests and land, based on the percentage in 2021. Of this area, 22% would be conifers and 78% broadleaves, based on planting proportions in 2020-21. The assumptions on woodland species class were based on Scottish woodland composition from the National Forest Inventory and assumed yield classes in the CCC Balanced Pathway scenario and BEIS GGR scenario modelling (Table 12-6). The area of woodland created did not change between the Central, High and Low scenarios, but the species YC assumptions did change.

Table 12-6: Public planting assumptions (species, yield class, management, spacing)

	Central Scenario	High growth scenario	Low growth scenario
Broadleaf planting	Sycamore/Ash/Birch, YC6, No-thinning, 2.5m spacing	Sycamore/Ash/Birch, YC10, No-thinning, 2.5m spacing	Sycamore/Ash/Birch YC4 No-thinning, 2.5m spacing
Conifer planting	Sitka spruce, YC16, Thinned, 2.0m spacing	Sitka spruce, YC20, Thinned, 2.0m spacing	Sitka spruce, YC14, Thinned, 2.0m spacing

The estimated total net carbon sequestration from woodland creation by 2045 in the Central scenario is -0.7 Mt CO_2e (-1.2 Mt CO_2e in the High growth scenario, and -0.5 Mt CO_2e in the Low growth scenario (Figure 12-10).

Figure 12-10: Total net carbon sequestration from woodland creation on Scottish national forests and land



12.1.3 Policy 3: Awareness-raising. We will continue to deliver a programme of farm-based events to demonstrate and support improved productivity through integration of farming and forestry enterprises - Indicative assessment

We suggest that this policy should be screened out at this stage as it is not possible to quantify associated impacts on GHG emissions. The assessment of the impact of this policy would depend on knowing how many farmers/foresters attending events, how many of them subsequently took action (e.g. through applying for targeted grants), and an assessment of whether this action was additional to what would have occurred in the absence of a programme of events. It is unlikely that this policy would affect woodland creation rates directly but an events programme could have value in influencing farmers' cultural beliefs and attitudes towards trees on farmland (see Staddon et al 2021 NEER020). As part of a suite of policies, such as Policy 6 and the policies and proposals under Agriculture Outcome 6, it could be anticipated to have a small positive impact on the uptake of woodland creation grants for small/farm woodland and agroforestry. However, there is not currently enough information to quantify this impact further.

12.1.4 Policy 4: Woodland standards. The Scottish Government will lead on the work with the UK and other UK Governments to maintain and develop a UK Forestry Standard that articulates the consistent UK wide approach to sustainable forestry. The Standard defines how woodland should be created and managed to meet sustainable forest management principles and provides a basis for monitoring. - Indicative assessment

We suggest that this policy should be screened out at this stage as it is not possible to quantify. The updated UK Forestry Standard is due to be published by the end of 2022. Creation and management of woodland to meet sustainable forest management principles could have either a positive or negative impact on net greenhouse gas emissions depending on the context, previous management and timescales under consideration.

12.1.5 Policy 5: Woodland carbon capture. The Scottish Government will further develop and promote the Woodland Carbon Code in partnership with the forestry sector, and will work with investors, carbon buyers, landowners and market intermediaries to attract additional investment into woodland creation projects and increase the woodland carbon market by 50% by 2025. –Full assessment

The target in the CCPU (2018-2032) is to increase the woodland carbon market by at least 50% by 2025. There were 3.791 million validated credits in the Woodland Carbon Code Registry in Scotland in March 2020, and interim statistics (March 2022) project a total of 5.5 million validated credits, with 8.9 million credits under development. This indicates that the woodland carbon capture target is achievable for 2025, although it should be noted that these figures include both the carbon units that can be sold and those that are allocated to the WCC buffer.

All WCC project areas are on private land and some areas receive additional funding from the SFGS and will already be included under Policy 1. Additional information is required to ascertain to what extent WCC project areas overlap with woodland created via grant-aided planting, and which areas are created solely with additional WCC funding. This was discussed with Scottish Government policy makers but resources did not permit the data collation and analysis within the project timeframe. WCC planting is additional to other woodland creation in carbon terms.

12.1.6 Policy 6: Forestry and woodland strategies. Forestry and woodland strategies continue to be prepared by planning authorities, with support from Scottish Forestry. They provide a framework for forestry expansion through identifying preferred areas where forestry can have a positive impact on the environment, landscape, economy and local people. - Indicative assessment

We suggest that this policy should be screened out at this stage as it is not possible to quantify. This policy will contribute to the attainment of policies 1 and 2. There are also potential interactions with Regional Land Use Partnerships (LULUCF Outcome 4/Policy 1) and the farm woodland proposals under Agriculture Outcome 6.

12.1.7 Proposal 1: Support forestry sector on plant and seed supply strategy to help meet the increased planting targets. A programme of technical innovation to develop and adapt modern horticultural practices will help improve seed preparation and handling, techniques to reduce environmental impacts, and increase nursery production. Funding to support increased production of young trees is available through the Harvesting and Processing grant which is now open to forest nurseries across GB with support from Defra. - Indicative assessment

It is likely that this proposal, if implemented, would result in a small positive impact on net greenhouse gas emissions and contribution to woodland creation due to reduced mortality of seedlings and young trees, reduced environmental impact and reduced need for importation from outside Scotland (with associated reduction in transport costs etc.). This benefit would only be quantifiable once trees have been established, rather than at the nursery stage. The CCPu Monitoring Compendium indicated that there has been good uptake of the grant scheme, with 158 grants claimed since 2016 (£3,155,134) and a further 238 approved (FGS Statistics January 2022).

12.1.8 Proposal 2: Forestry and Land Scotland will begin development of a new approach to woodland investment with a view to acquiring more land to establish further woodland on Scotland's national forests and land for the benefit of future generations and to optimise carbon sequestration. This includes partnering with private sector and other organisations to enhance scale and funding of carbon capture projects. - Indicative assessment

Forestry and Land Scotland have indicated that they will explore how to enhance their existing peatland restoration programme, ensuring that any forest removals on peatland are replaced by new forest planting on suitable land (CCPU, p. 178). This would be additional to planned woodland creation. An area of 5,570 hectares of peatland with woodland cover on FLS land has been rewetted 2015-2020 (Peatland Action and FLS data).

Planting an equivalent area (with a five year offset between rewetting and planting) with new conifer forest on mineral soil (assumed Sitka spruce YC12) would result in carbon sequestration of 0.4 Mt CO_2e by 2045. The equivalent area of Sitka spruce YC8 (assumed aged 40 years old in 2020) would have a total carbon sequestration of 0.05 Mt CO_2e in 2020 and 0.7 Mt CO_2e by 2045. (These numbers are for biomass carbon only and do not take account of soil carbon emissions or removals beyond establishment emissions for new forest on mineral soil).

12.2 LULUCF Outcome 2: Increase the use of sustainably sourced wood fibre to reduce emissions by encouraging the construction industry to increase its use of wood products where appropriate.

12.2.1 Policy 1: In collaboration with the private forest sector and other public sector bodies the Scottish Government will implement the Timber Development Programme through an annual programme of projects that support the promotion and development of wood products for use in construction. - Indicative assessment

We suggest that this policy should be screened out at this stage as it is not possible to quantify, and is an enabling policy rather than one that has a direct impact on emissions. Further information is needed on how much of the sustainably sourced wood fibre will come from within Scotland/the UK, and the quantified targets of the Timber Development Programme. The CCPu Monitoring Compendium lists the indicator for this Outcome as "Off-Track" The commentary for this indicator is that an estimated 2.09 million cubic metres of Scottish produced sawn wood and panel boards were used in used in construction in 2020 (the indicator milestone was 2.6 million m^3), due to the COVID-19 pandemic. The review on wood in construction in Scotland by Kerkvliet-Hermans (2020) discusses the high proportion of timber-framed new builds in Scotland compared to the rest of the UK (83% vs. 28% in 2016) and the potential for increased timber substitution and associated CO_2 emission reductions compared with high CO_2 footprint construction materials such as concrete and steel.

12.3 LULUCF Outcome 3: To enhance the contribution of peatland to carbon storage, we will support an increase in the annual rate of peatland restoration

12.3.1 Policy 1: Restoration grants: We will provide grant funding to support eligible land managers to deliver peatland restoration. Levels of funding will enable at least 20,000 hectares of peatland restoration per year. We will undertake research to inform where restoration can deliver the greatest emission savings per hectare. – Full assessment

The 2018 Climate Change Plan set a peatland restoration target of 250,000 ha by 2030, with a target of 50,000 ha by the end of 2019-20. The Committee on Climate Change have suggested an even more ambitious target of around 50,000 ha of peatland restoration per year in the 2021 Progress Report to Parliament (CCC 2021)). Data on peatland restoration in Scotland provided by a peatland restoration compendium from 2000-2012 given in Evans et al. (2017), activities from 2013-2019 compiled by Peatland Action, and a UKCEH Google Earth derived dataset on peat extraction restoration from 1990-2019, totalled 35,595 ha in 2019 (see Table A 3.4.26 in Brown et al. 2021). These data represent restoration actions, such as ditch blocking and damning, carried out to raise the water table to the bog surface, and do not include peatland management activities (e.g., scrub removal, grazing management) that would not cause a site to transition to a rewetted peatland.

There is limited evidence on the timeframe for UK rewetted peatlands to transition to a naturally functioning state, so the interim approach used in this study (and the UK GHG inventory) is to assume that peatland restoration (rewetting) results in an immediate transition to a "Rewetted" emission factor (EF) in the year that the activity to raise the water table occurs. The Rewetted Bog (3.91 t CO_2e) and Rewetted Fen (8.05 t CO_2e) EFs are derived from studies on formerly degraded sites such as plantation forest, extraction sites, cropland, and pastoral grassland, and thus the rewetted condition categories retain quite high CO_2 and/or CH_4 emissions (Brown et al. 2023; Evans et al. 2023) compared with near-natural peatlands (NN bog = -0.02 t CO_2e; NN Fen = -0.93 t CO_2e). No timelines for the transition from the Rewetted Bog/Fen EFs to Near-Natural EFs are currently available. However, for restoration of less heavily degraded sites, i.e. Modified (Heather and Grass Dominated) Bog, a restoration transition to Rewetted Modified Bog is applied in the year of activity, which assigns the same EF as Near-Natural Bog (Brown et al. 2022; Evans et al. 2022).

Initial peat condition areas, and associated emission factors, for 2019 were taken from the 1990-2019 LULUCF GHG inventory (Brown et al. 2021), except for Forestry which employs the combined Tier 2 EF from a literature review and meta-analysis of direct CO_2 flux measurements given in Evans et al. (2017) rather than outputs from the Tier 3 CARBINE Model, which was not possible to employ in this analysis, summed with the EFs for indirect CO_2 (from dissolved organic carbon and particulate organic carbon), CH_4 and N_2O employed in the 1990-2019 LULUCF GHG inventory. The Tier 2 EF for direct CO_2 for Forest Land on peat (7.39 tCO_2e ha^{-1} yr^{-1}) from Evans et al. (2017) is higher than the CARBINE implied organic soil EFs (2.54 tCO_2e ha^{-1} yr^{-1} in 1990 to -1.79 tCO_2e ha^{-1} yr^{-1} in 2019) and is possibly a conservative estimate of emissions as it does not explicitly account for lifecycle differences of trees. The decreasing trend in the organic soil carbon EF from CARBINE is due to an increase in age of forests on organic soils with increasing tree inputs (litter, roots etc) counterbalancing organic soil decomposition. The CARBINE model uses the best-case scenarios of yield classes on organic soils, with minimal disturbance associated with forestry on peat, and thus is probably overly optimistic in terms of carbon capture in trees growing on peat and continued loss of carbon from soils over time due to drainage. In both cases, the Tier 2 and Tier 3 EFs on organic soils have a high level of uncertainty due to limited field flux data and require further research.

A combination of IPCC default (Tier 1) and UK-specific (Tier 2) emission factors are used for estimating emissions from peatland/organic soils in the inventory, depending on the availability of UK data. The emission factors and associated uncertainties vary for each peatland condition category depending on the number of studies available for each category (see section A.3.4 of the National Inventory Report Annexes, Brown et al. 2022). The EFs used are subject to periodic updates to incorporate new UK data as they become available, for instance an EF update was implemented in the 1990-2021 inventory, which affected all peatland condition categories (see Evans et al. 2022).

Overall uncertainty in the emissions estimates for peatlands stem from the uncertainties in the emissions factors used, described above, uncertainties in the mapping of peat extent, and uncertainties in the estimates in restored areas since accounting of restoration began in 2000. The peat condition maps for Scotland used in the GHG inventory were developed for the BEIS Wetlands Supplement ((TRN860/07/2014) Project (Evans et al. 2017). The uncertainties associated with the activity data cannot objectively be quantified due to the limited data sources so expert judgement was used to assign peatland condition classes to low, medium and high uncertainty: 10%, 30% and 60%, respectively (see Brown et al 2022 for further details)., however an overall assessment of high/medium uncertainty was given by the authors of the unified peat extent and condition map for use in the inventory (R. Artz, JHI, personal communication to BEIS 25.04.2019).

The CCPu Monitoring Compendium indicator for this policy, of hectares of peatland restored per year, shows that progress towards the policy target is off-track but forecast annual restoration areas are slowly increasing towards the 20,000 hectare target (5,658 in 2020-21, 8,000 in 2021-22, forecast 11,000 in 2022-23 according to the CCPu Monitoring report published May 2022). We have used the average annual rate of peatland restoration from the data sources outlined above to guide realistic restoration scenarios. For the Central peatland mitigation scenario, which we broadly aligned with the BEIS LULUCF 2019 inventory projection assumptions, peatland rewetting for forest, cropland, intensive grassland, settlement and peat extraction continued at 2018-2020 average rates to capture recent increases in restoration activity, a total of 1,615 ha/yr. Most of the peatland restoration (21,112 ha) is applied to eroded modified bog, modified bog, and extensive grassland in proportion to their relative area in 2019, to reach 250,000 ha of peatland restoration by 2030 and a total of 590,909 ha by 2045 (Table 4). It is however important to note that Scottish Government policy is developing and may be updated in the future.

In the High growth mitigation scenario, peatland restoration was targeted at higher-emitting land categories, incorporating an ambitious reduction of peat extraction to zero by 2030 from a stretch BEIS LULUCF emissions projection scenario, and a 40% reduction in cropland and intensive grassland by 2045 from the UK Sixth Carbon Budget. However it is important to note, that unlike England and Wales, Scotland does not currently have a policy in place to ban the sale of peat, therefore this level of ambition may be unrealistic. There is considerable uncertainty associated with the estimates of net emissions from land use. In particular, the current scientific view is that the area of grassland on peat may be overestimated. If this is the case, the impact on net emissions from the combination of a reduction in peat extraction and a reduction in intensive grassland can only be satisfactorily predicted by revised, careful modelling.

Forest on organic soil was restored using an annual rate of 2,523 ha/yr given in 2019. We split the remaining restoration areas among semi-natural peatlands and extensive grassland in the uplands according to their 2019 areas. A total peatland area of ca. 1,947,000 ha is reported in the 2019 GHG inventory (Brown et al. 2021 & 2022). A cumulative area of 250,000 ha of restoration is simulated by 2030, which continues at the same rate across the peat condition categories until 2045 to provide 590,909 ha of restoration in total (Table 4), which is consistent with the 600,000 ha of restorable peatland quoted in the CCC (2022) report to Scottish Parliament. This does not reach the full restoration of upland bog by 2045 recommended in the Sixth Carbon Budget, with ca. 470,000 ha of modified bog remaining.

The Low growth scenario employs the average rate of restoration, 4,760 ha/yr, from 2018-2020, which continues at a constant rate to 2030, with restoration focused in the uplands (comprising 1,496 ha of annual forest to bog restoration, and the remaining areas split between eroding bog, modified bog, and extensive grassland in proportion to their relative area in 2019). No restoration occurs on lowland pastoral land, cropland, or peat extraction sites (Table 4).

Table 12-7: Projected changes in area in hectares of peatland categories due to peatland restoration between 2020 and 2045 for three emission reduction scenarios.[63]

Peat Condition Category	Scenario Area Changes, ha		
	Low	Central	High
Forest	-16,461	-38,908	-65,586
Cropland	0	0	-2,265
Eroding Modified Bog (Bare Peat)	-1,461	-22,346	-18,183
Modified Bog (semi-natural heather & grass dominated)	-33,144	-506,827	-412,400
Intensive Grassland	0	-292	-28,903
Extensive Grassland (combined bog/fen)	-1,291	-19,740	-16,062
Extracted Industrial	0	-1,222	-2,856
Extracted Domestic	0	-1,575	-44,654
Settlement	0	0	0
Change in peat condition	**-52,357**	**-590,909**	**-590,909**
Rewetted Bog	17,922	82,569	128,423
Rewetted Fen	1,291	1,514	50,086
Rewetted Modified Bog	33,144	506,827	412,400
Change in Restored Area	**52,357**	**590,909**	**590,909**

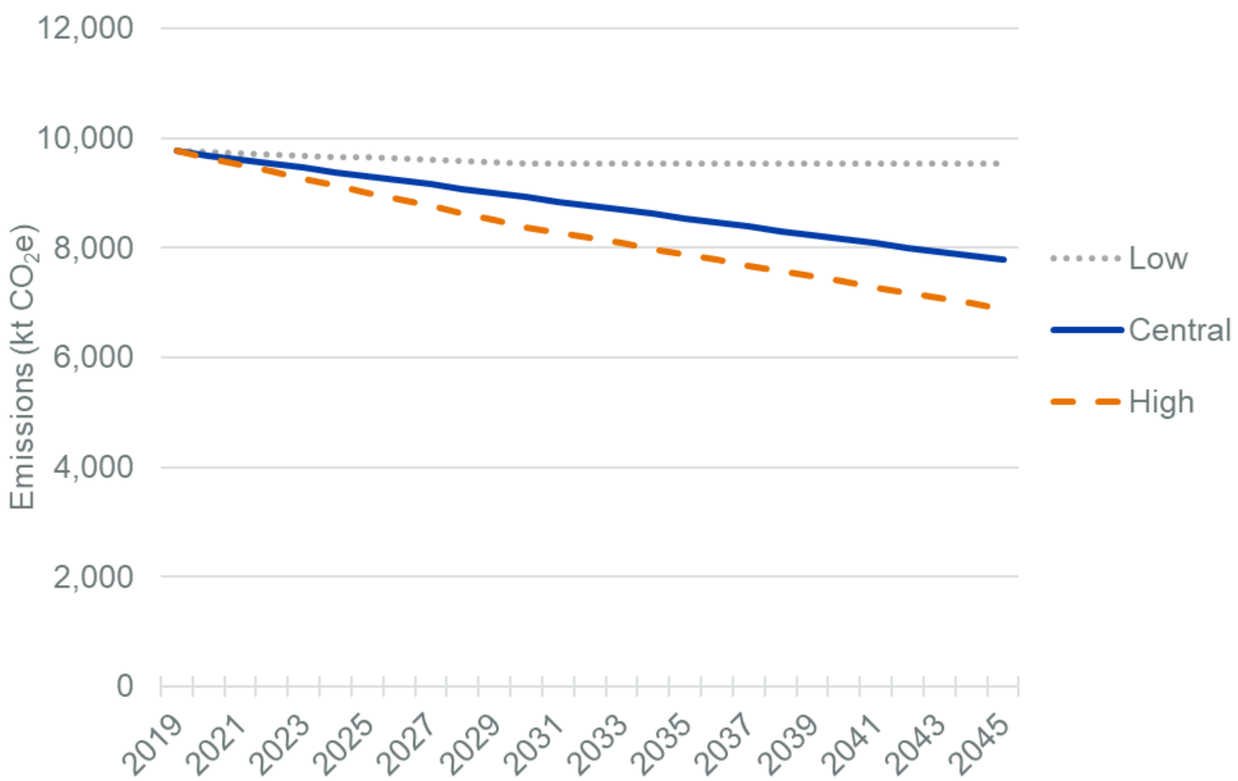
The estimated GHG emissions saving from peatland restoration by 2045 in the Central scenario is 1.988 Mt CO_2e (2.881 Mt CO_2e in the High growth scenario, and 0.218 Mt CO_2e in the Low growth scenario). Abatement in the Central scenario is mostly due to modified bogs (77%), with the remaining emissions reduction due to forest (13%), extensive grassland (9%), and peat extraction (1%). Most of the abatement (43%) in the High scenario is from modified bogs, however restoration of cropland, intensive grassland and peat extraction provides a high degree of abatement (37%) while representing a small proportion (13%) of the restored area. However, it should be acknowledged that the immediate transition to a Rewetted Emission Factor, discussed above, may over-estimate how quickly restoration actions can reduce GHG emissions, particularly in formerly degraded sites. That said, the inventory “Rewetted” EFs include studies from a range of heavily modified starting conditions and subsequent recovery periods following restoration, which overall retain elevated GHG emissions, and do not necessarily represent the end state of peatland restoration, which acts to moderate the expected outcome of restoration. This modelling approach is likely to be updated when further data are available on the successful outcomes of restoration (rather than just actions) and the transition period for the reestablishment of the CO_2 sink in restored peatlands, which may be on the order of decades (e.g. Nugent et al. 2019; Alderson et al. 2019).

The remaining emissions reduction is due to rewetting of woodland (15%), and extensive grassland (5%). The Low growth scenario projects a small decrease in emissions based on 2018-2020 levels of restoration, with 49% of the abatement attributed to forest to bog

[63] If the total areas are divided by 26 years (2020-2045) for the High and Central Scenarios and 11 years (2020-2030) for the Low scenario the values will match those in the text.

restoration, 46% of emissions reduction due to restoration of modified bogs in the uplands, and 5% of the abatement attributed to restoration of extensive grassland to rewetted bog. These estimates do not account for the potential impacts of climate change (e.g. drought, fire, heatwave events) on peatland hydrology, plant communities, and biogeochemical functioning, which may increase peatland emissions in the future. Drained peatlands, in particular, are expected to have lower resilience to climate change compared with undrained and restored areas (e.g. Lees et al. 2021).

Figure 12-11: Organic soil emissions scenarios from 2019-2045.



12.3.2 Policy 2: Awareness raising: Working through partnership, we will put in place tools and information to promote peatland restoration and develop the capacity, skills and knowledge of land owners, land managers, contractors and others to deliver peatland restoration. - Indicative assessment

We suggest that this policy should be screened out at this stage as it is not possible to quantify associated impacts on GHG emissions, for the same reasons as LULUCF Outcome 1/Policy 3.

12.3.3 Policy 3: With partners, refresh our vision for Scotland's peatlands and review peatland restoration support mechanisms to overcome embedded barriers and improve how we fund and deliver this activity- Indicative assessment

We suggest that this policy should be screened out at this stage as it is not possible to quantify associated impacts on GHG emissions, for the same reasons as LULUCF Outcome 1/Policy 3.

12.3.4 Policy 4: Phase out the use of peat in horticulture by increasing uptake of alternative materials, undertaking stakeholder engagement to understand transitional challenges, to improve the uptake of alternatives and develop a time-scaled plan–Full assessment

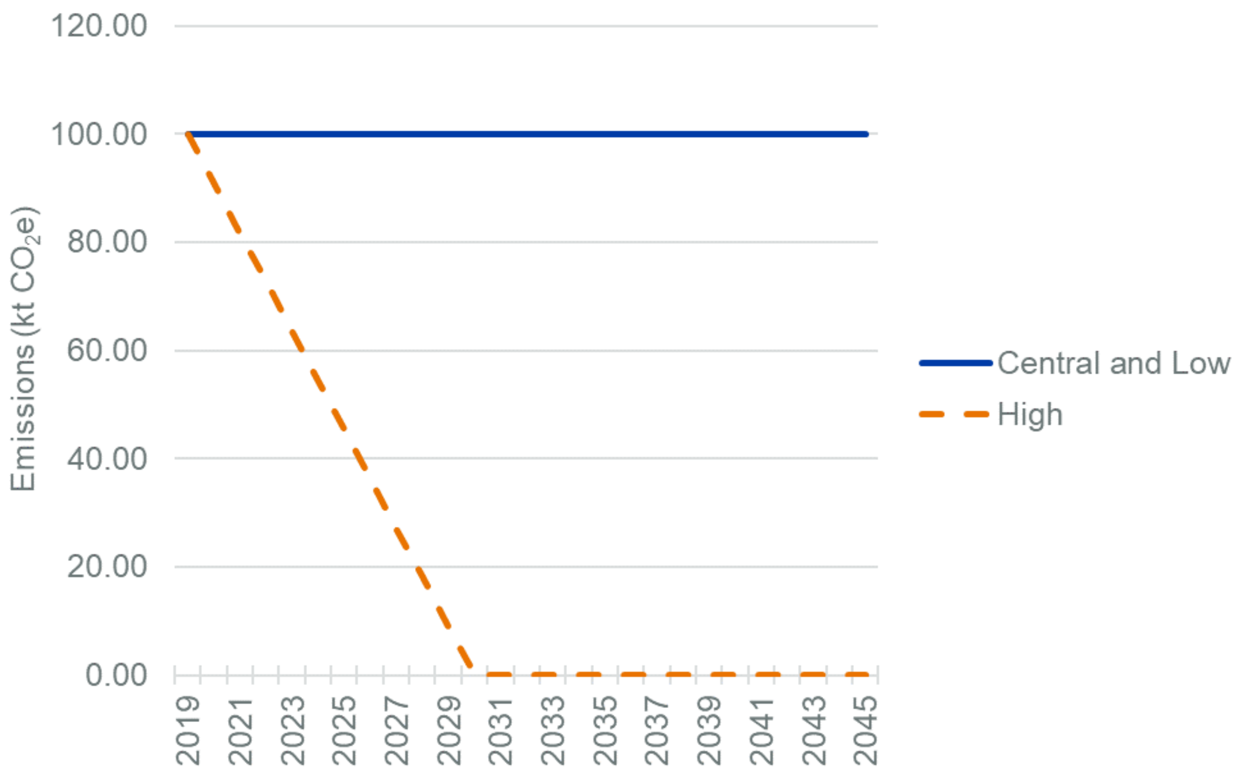
Historical peat extraction in Scotland for horticultural uses in compost has remained fairly steady over the last 30 years, with 1,106 and 1,082 ha of active horticultural peat production reported in 1990 and 2019, respectively (Brown et al. 2021, pers. comm.; Neil Bragg, chair of Growing Media Association, Jan. 2021). These areas are included above in the Central projection of onsite emissions from organic soils shown in Figure 12-11.

As stated above in the Policy 1 section, for the Central/Business-as-usual and Low growth projection we assume no restoration of active/operational extraction sites, resulting in zero reduction in carbon lost by oxidation of the harvested peat. In the High growth projection, all horticultural extraction sites are restored by 2030, reducing off-site emissions to zero by 2030 (Figure 12-12).

The Scottish Government's National Planning Framework 4, adopted on 13 February 2023, sets out that new commercial peat extractions, including new extensions to existing sites will not be supported, except in exceptional circumstances and only then, when the peat to be extracted is supporting the whisky industry. In addition, the CCC (2021) report to the Scottish Parliament goes further, and recommends new legislation to ban the use of peat in compost. No licence information was available on peat extraction sites to indicate site closure dates in Scotland.

Offsite emissions from horticultural peat extraction are not included in Figure 12-11, and so we present them separately in Figure 12-12. Offsite emissions in 2019, estimated using a carbon density in wet peat of 0.0641 tC/m^3 multiplied by the extracted peat volume of 425,372 m^3 derived from the British Geological Survey UK Kingdom Minerals Year book (Brown et al. 2021), and converted to CO_2 equivalents resulted in an emission of 99,980 t CO_2 (Figure 0-8). Updated data from a Growing Media Association report (GMA 2021) used in the 1990-2020 inventory provides a lower estimate of 243,671 m^3 (equivalent to an emission of 57,270 t CO_2) from these sites in 2019 (Brown et al. 2022). However, for consistency with other data sources we have used the Brown et al (2021) extraction volumes as a conservative starting point for the projections.

Figure 12-12: Offsite carbon emissions from horticultural peat extraction scenarios from 2019-2045.



12.3.5 Policy 5: Our Position Statement on National Planning Framework 4 confirmed our current thinking that through the planning system we will not support applications for planning permission for new commercial peat extraction for horticultural purposes, we are looking at strengthening controls on development on peatland and we will help facilitate restoration through permitted development rights- Indicative assessment

Scotland's Fourth National Planning Framework is now adopted, which includes policy on restricting peat extraction on new commercial sites, and limiting renewals of licences on existing sites, with exceptions for industries of national importance or where there is no reasonable substitute. We suggest that this policy should be screened out at this stage as it is not possible to quantify associated impacts on GHG emissions, which would require detailed information on licencing agreements.

12.3.6 Proposal 1: Develop opportunities for private sector investment in peat restoration, engaging with sectors to establish investment pathways, enabling both public and private sector to invest in a range of measures to help mitigate effects of climate change- Indicative assessment

We suggest that this policy should be screened out at this stage as it is not possible to quantify associated impacts on GHG emissions, as far as the development of investment opportunities goes.

12.3.7 Proposal 2: Explore how best to restore all degraded peat in the public estate and also within formally designated nature conservation sites, including through statutory mandate. - Indicative assessment

We suggest that this policy should be screened out at this stage as it is not possible to quantify associated impacts on GHG emissions without an estimate of the area of degraded peat in the public estate (currently being undertaken by NatureScot).

12.3.8 Proposal 3: Explore the development of a Peatland Restoration Standard to ensure best practice and continuous development in the success and effectiveness of peatland restoration- Indicative assessment

We suggest that this policy should be screened out at this stage as it is not possible to quantify associated impacts on GHG emissions. NatureScot are developing a Technical Compendium that may provide the basis for the Peatland Restoration Standard.

12.4 LULUCF Outcome 4: We will establish pilot Regional Land Use partnerships

12.4.1 Policy 1: Establishment of pilot Regional Land Use Partnerships to help ensure that we maximise the potential of Scotland's land to help achieve net zero. Publication of Scotland's third Land Use Strategy. - Indicative assessment

Pilot Regional Land Use partnerships have been established (Highland Council Region, Cairngorms National Park, Loch Lomond and Trossachs National Park, North East Region and South of Scotland). We suggest that this policy should be screened out at this stage as it is not possible to quantify associated impacts on GHG emissions, although it will contribute to the delivery of other policies/proposals considered here. The CCPu Monitoring Compendium does not have indicators for this policy outcome.

12.5 Agriculture Outcome 6: Carbon sequestration and existing carbon stores on agricultural land have helped to increase and maintain our carbon sink

The CCPu Monitoring Compendium lists the indicators for this Outcome as on-track for area of woodland on agricultural land and off-track for hectares of peatland restored per year (see LULUCF Outcome 3/Policy 1).

12.5.1 Policy 1 - Explore with the farming and forestry sectors how best to increase planting of trees and hedgerows which optimise carbon sequestration, including the role of agroforestry. - Indicative assessment

The CCPu Monitoring Compendium describes progress in launching the Integrating Trees Network and funding additional support for integration of small woodlands on agricultural land. However, we suggest that this policy should be screened out at this stage as there is insufficient information to quantify direct impacts on carbon sequestration[64]. The commentary under LULUCF Outcome 1/Policy 3 also applies here. This policy will interact with other policies/proposals targeted at increasing tree planting on agricultural land.

[64] The ClimateXChange report on agroforestry in Scotland (Perks et al. 2018) concluded that the impact of agroforestry on carbon sequestration is highly context specific, so information on location, soil type, tree species, density of planting and of stocking would be required for a robust quantification.

12.5.2 Proposal 1 - Investigate the feasibility of payment for carbon sequestration taking into account any existing schemes such as the woodland carbon code as a means of encouraging the uptake of carbon sequestration on farms. - Indicative assessment

We suggest that this policy should be screened out at this stage as there is insufficient information to quantify direct impacts on carbon sequestration. The CCPu Monitoring Reports 2021 Compendium notes that a significant number of farmers are already selling carbon credits under the Woodland Carbon Code. This proposal is also lined to LULUCF Outcome 1/Policy 5.

12.5.3 Proposal 2 - Woodland cover on suitable agricultural land- Full assessment

Almost all forest creation occurs on agricultural land, some of it on pastures, and the majority on extensively grazed semi-natural grasslands. Therefore all woodland cover on suitable agricultural land is a subset of the woodland cover reported under LULUCF Outcome 1. The farm woodland area reported in Forestry Statistics reports are not clearly defined, and is likely to be a combination of grant-aided planting under other SFGS woodland creation options, non-grant aided planting/regeneration and variations in the area of farmland reported as woodland (which does not necessarily indicate a change in woodland area). The area planted under the “Small or Farm Woodland” option of the Scottish Forestry Grant Scheme is only 390 hectares since 2017 (473 hectares has been approved), and there has been none under the “Agroforestry” option.

In the 1990-2020 National GHG Inventory (Brown et al. 2022), for 2011-2020 an estimated 27.5% of Scottish annual woodland creation occurs on agricultural land (cropland and pasture land). This estimate comes from a land-use change dataset produced from data assimilation of multiple land-use/land-cover data sets (See Brown et al 2022 1990-2020 NIR). This proportion can be used to estimate the annual increase in woodland on agricultural land (Table 12-8). These rates of woodland creation would give an additional 51,179 hectares of woodland cover on agricultural land by 2045. This represents 2% of the area of agricultural land (arable, mixed agriculture and improved grassland Land capability classes) potentially available for woodland expansion in Sing and Aitkenhead (2020).

Table 12-8: Recent and projected annual increase in woodland on agricultural land in Scotland

Year	Total annual woodland creation, ha/yr	Annual woodland creation on agricultural land, ha/yr
2020	11,714	3,221
2021	13,125	3,609
2022	14,625	4,022
2023	16,125	4,434
2024	17,625	4,847
2025-2031	18,000	4,950
2032-2045	326	90

The estimated total net carbon sequestration from woodland creation on agricultural land by 2045 in the Central scenario is 3.3 Mt CO_2e (4.4 Mt CO_2e in the High growth scenario, and 2.4 Mt CO_2e in the Low growth scenario). This assumes that woodland created on agricultural land has the same overall composition of species and yield classes as the total area of woodland creation.

12.5.4 Proposal 3 - Building on the successful work integrating woodland with farming businesses, help remove barriers for those on agriculture holdings, particularly in the tenanted sector who want to engage in woodland creation, including exploring the potential to reform legislation where appropriate. - Indicative assessment

The CCPu Monitoring Compendium reports that a working group on “Tenants and Trees” has been established and there is ongoing work in this area. Although an additional £1.5M has been made available to further support the integration of small woodlands on farms and crofts, further details are needed on how this will be spent and how success will be monitored (no current indicators associated with this proposal). We suggest that this policy should be screened out at this stage as there is insufficient information to quantify direct impacts on carbon sequestration.

12.5.5 Proposal 4 - Work with stakeholders on options to increase peatland restoration on suitable agricultural and crofting land, to support delivery of policies in the LULUCF chapter. We will map peatland against this land which will allow modelling options for land-use change and inform opportunities for targeted support of peatland restoration and management. - Indicative assessment

The CCPu Monitoring Compendium describes work underway to assess land use classifications, capability and the potential for restoring peatland which will inform the setting of a baseline and targets. We suggest that this policy proposal should be screened out at this stage as there is insufficient information to quantify associated impacts on GHG emissions.

12.5.6 Proposal 5 - Explore options for land-use change to optimise uses beyond traditional farming and food production to multi-faceted land use including forestry, peatland restoration and management and biomass production. - Indicative assessment

The CCPu Monitoring Compendium does not list any indicators for this proposal. Other proposals mention that work is underway to assess land use classifications and capability and links with the pilot Regional Land Use Partnerships (LULUCF Outcome 4) which will inform the setting of a baseline and targets for this proposal. We suggest that this policy proposal should be screened out at this stage as there is insufficient information to quantify associated impacts on GHG emissions.

12.6 Negative Emissions Technologies (NETs) Outcome 3: Bioenergy: a cross-sectoral approach for the appropriate and sustainable use of biomass in energy applications is agreed and implemented (taking into account competing land and feedstock uses)

12.6.1 Policy 2: In 2021, building on the Bioenergy Update, we will establishing a cross sectoral Bioenergy Expert Working Group to consider and identify the most appropriate and sustainable use for bioenergy resources across Scotland. It will also assess the volume of bioenergy resources that we can grow or produce within Scotland, and confirm the level of import that we believe is compatible with a sustainable global trade in bioenergy. - Indicative assessment

We suggest that this policy should be screened out at this stage as it is not possible to quantify the impact of the Bioenergy Expert Group on associated GHG emissions at this stage.

A Bioenergy Action Plan is due for completion by the end of 2022, and draft analysis/text/assumptions are not yet available. In discussion, the policy contacts in the sector expressed concern that analysis of potential GHG mitigation in this project could contradict and undermine the more detailed analysis that will be published with the Bioenergy Action Plan.

Net emissions from combustion of bioenergy crops would be reported under the Energy sector of the national GHG Inventory. However, carbon sequestration in the biomass of perennial bioenergy crops such as Miscanthus grass and short-rotation coppice and the soils would be reported in the LULUCF sector, and could constitute an additional carbon sink, depending on the management employed (see Thomson et al. 2021 for worked examples).

12.7 Adjustments required to match 1990-2020 GHG inventory

The estimated emissions from the policies are for activities from 2020 onwards. They do not include other LULUCF emissions from historic land management and land-use change[65], which will continue to contribute to overall LULUCF GHG emissions between 2020 and 2050. Projected emissions to 2050 for the LULUCF sector have been calculated based on the 1990-2019 inventory, but equivalent projections are not available for the 1990-2020 inventory. Methodological changes in the 1990-2020 inventory mean that it is not possible to use the 1990-2019 projections without adjustments.

The adjustments required to ensure consistency between the policy emissions and the 1990-2020 inventory are as follows:

- Replacing the estimated peatland policy emissions for 2019 and 2020 in the Central, Low and High scenarios with the appropriate values (by source) from the 1990-2020 inventory.
- Including the other LULUCF net emissions arising from historic land management and land-use change from 2021 onwards. Adjustments have been applied for each land category and GHG combination based on the difference in values for 2020

[65] Set out in the bullet point list below, and, activities that had happened before 2021 that will still produce GHGs post 2021.

between the projections based on the 1990-2019 inventory and the 1990-2020 inventory. The additional sources/sinks are:

- Net carbon stock changes and emissions from existing forests on mineral soils and biomass carbon stock change in existing forests on organic soils;
- Net carbon stock changes and emissions from cropland, grassland and settlement on mineral soil due to land use change and land management;
- Offsite emissions from horticultural peat, emissions from grassland converted to flooded land (on mineral soil), biomass burning and biomass losses from rewetted forests;
- Emissions from biomass burning (wildfires and controlled burning due to deforestation) on forest, cropland and grassland;
- Emissions from changes in the harvested wood products pool (from existing forests); and
- Indirect N_2O emissions from the LULUCF sector.

- A small adjustment to net carbon stock change from existing forests in 2019 (3 kt CO_2e) and 2020 (12 kt CO_2e) was added to account for methodological differences between the inventory and the projection calculations.

The net peatland emissions include N_2O emissions from intensive agriculture (cropland and improved grassland). Under the IPCC reporting framework for the national GHG inventory these emissions (227 kt CO_2e) are reported under the Agriculture sector rather than the LULUCF sector.

There remains a large jump in the net emissions timeseries post-2021. This is due to the implementation of Tier 2 emission factors for forest on organic soils in the policy projections: the national GHG inventory and the 1990-2019-based projections use the CARBINE method (see further discussion in the text under LULUCF Outcome 3/Policy 1. The Tier 2 EF is higher and static over time, compared with the CARBINE method which takes account of forest growth and inputs and produces a variable implied emission factor. We would recommend that the Scottish Government commission further analysis using either the CARBINE model, or an improved proxy method, including a comparison of model uncertainties, to resolve these inconsistencies.

12.8 Approach to align the LULUCF projections with the SG GHG projections model

In the overall Scottish Government Projections model, an offset of -4073.866 kt CO_2e is applied to output of the LULUCF modelling work from 2021 onwards to remove this large jump in emissions and to provide a smooth emissions trajectory that allows a partial comparison with the Scottish Sector Emissions Envelope for LULUCF.

This offset was applied by the Ricardo modelling team.

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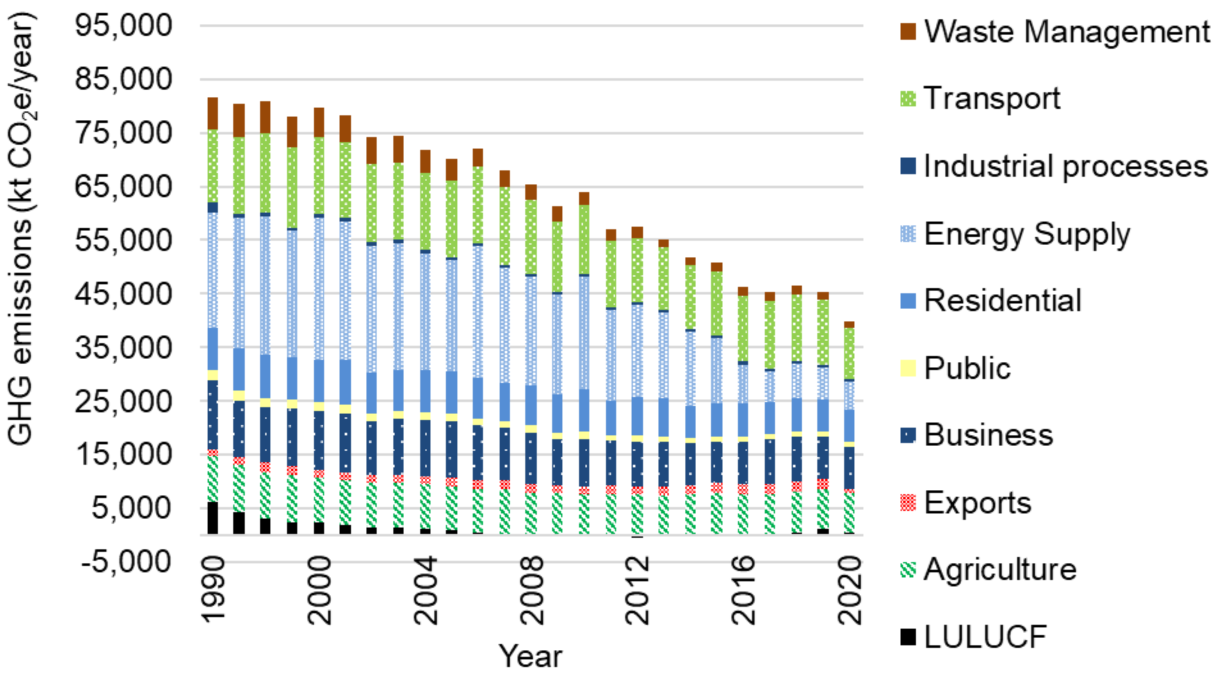
Appendix 2. Historical GHG emissions

This section presents Scotland's historical GHG emissions from 1990-2020[66]. Note: The sectors as defined in the GHG inventory do not align to the sectors as used in the CCPu (e.g., there is no "buildings" sector). Sectoral reallocations were undertaken for the purpose of the emissions projections, but were not applied to historical data.

Figure 12-13 .Historical GHG emissions for Scotland from 1990-2020

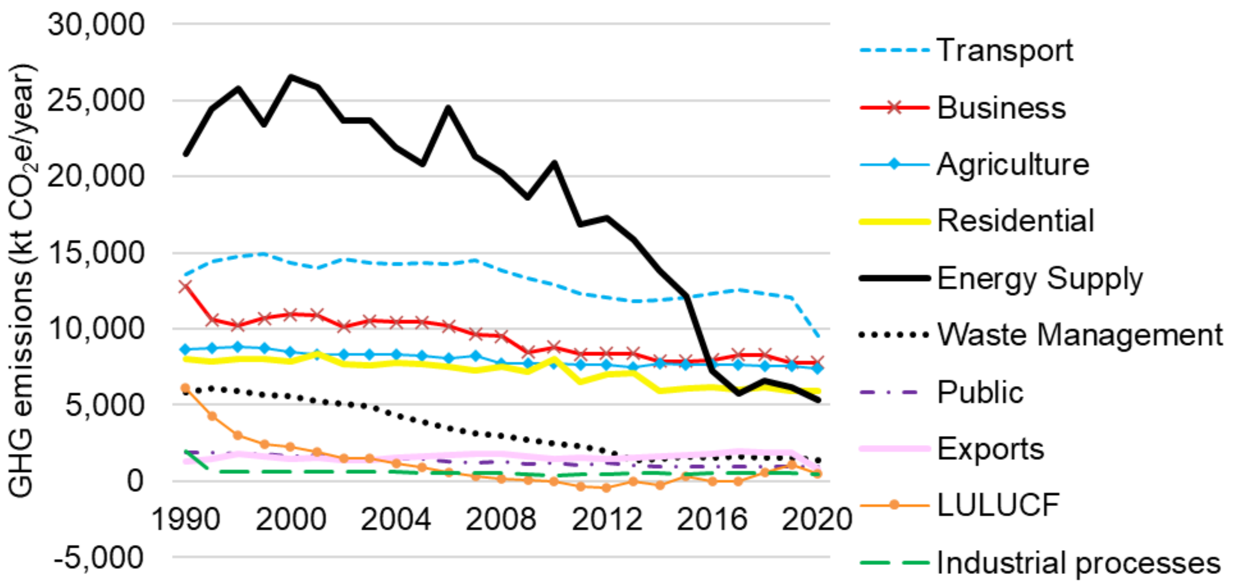


Total emissions for Scotland as a whole have decreased from 81,609 ktCO_2e in 1990 to 39,952 ktCO_2e in 2020. While 2020 was the latest inventory year available, 2019 is used as the base year in this work because 2020 is considered an anomalous year (due to the COVID-19 pandemic). In 2019, total emissions for Scotland as a whole were 45,401 ktCO_2e. The chart below shows the trend in total emissions over time, with sectoral contributions shown.

Trends over recent years for individual sectors vary, as shown in the chart below. The most important historical trend to note is the significant downward trend for 'Energy Supply' between 1990 and 2020. More gradual decreases have been seen in other sectors.

[66] National Atmospheric Emissions Inventory, *'Greenhouse Gas Inventories for England, Scotland, Wales & Northern Ireland: 1990-2020'* (2022). Available at: https://naei.beis.gov.uk/reports/reports?report_id=1080

Figure 12-14. Historical GHG emissions for Scotland, by sector, from 1990-2020



Appendix 3. Assessment methodology for Buildings Sector policies and outcomes

Details of the modelling assumptions used to calculate GHG impacts from policies and outcomes in the Buildings sector are set out below. These are grouped by topic/theme.

12.10 Existing buildings

12.10.1 Upgrading fabric efficiency

We have sought to calculate (a) the impact of specific policies/programmes, as well as (b) the overall impact of achieving the EPC rating targets. We understand there is likely to be a 'gap' between these, which will need to be met via other means.

For the purpose of this assessment, we propose to use EPC ratings as a proxy for fabric efficiency and have modelled heating system replacements separately, although we acknowledge that EPC upgrades can cover a variety of different interventions, including heating system replacements.

To avoid double-counting the impact of fabric efficiency measures, we have assumed that initiatives, policies, and funding allocated for building fabric and efficiency upgrades will contribute towards the EPC rating targets rather than resulting in additional energy demand or GHG reductions.

Further details are provided below.

(a) Following discussions with Scottish Government, it is understood that there are no specific targets for the number and type of measures that the schemes are likely to fund. For policies/programmes that have already been implemented and are planned to continue in future, we have therefore reviewed historic uptake rates or statistics (where available) and assumed that:

- Rates of uptake continue proportional with the amount of funding that is available going forward
- The technology split (or % of interventions by type) remains the same (apart from fossil fuel heating systems – discussed further below).

To estimate the impact of ECO measures, we have referred to statistics on the number and type of installations per year.[67] The overall impact on energy use and emissions has been calculated based on statistics in the National Energy Efficiency Database.[68] These have been used to generate an annual average estimate of the change in energy demand that results from the ECO scheme. Per Scottish Government feedback, we have assumed that the ECO will extend through 2026.

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[67] BEIS, *'Household Energy Efficiency Statistics: Headline Release June 2022 – Table 3.3'* (2022). Available at: https://www.gov.uk/government/statistics/household-energy-efficiency-statistics-headline-release-june-2022

[68] BEIS, *'National Energy Efficiency Data Framework: Impact of Measures Data Tables'* (2021). Available at: https://www.gov.uk/government/statistics/national-energy-efficiency-data-framework-need-impact-of-measures-data-tables-2021

Comments provided by Scottish Government to Ricardo via email on 11 May 2022 indicated that the Bute House Agreement increased the HIBS Social Housing Decarbonisation funding from £1.6bn to £1.8bn, and that it will include:

- At least £465m to support those least able to pay
- £200m for the Social Housing Net Zero Heat Fund
- £200m for the Scottish Green Public Sector Estate Scheme

The impacts of the £465m HIBS Social Housing Decarbonisation funding, £200m Social Housing Net Zero Heat Fund, and existing HiBS domestic and SME Delivery Schemes have been modelled as a policy package (Package B1) based on the approach described above. We have referred to statistics on the measures implemented as part of the Warmer Homes Scotland (WHS), Area-Based Schemes (ABS), and Home Energy Scotland (HES) schemes (provided by Scottish Government) to calculate the average annual number of installations under each scheme. As with the ECO (see above), the overall impact on energy use and emissions has been calculated based on statistics in the National Energy Efficiency Database (NEED). We have then scaled the number of measures based on the amount of additional funding that will be available.

(As noted previously, we have generally assumed that the split of technologies remains the same. However, per Scottish Government feedback, we understand there is a commitment to phase out the use of fossil fuel heating systems. Therefore, where funding has previously been used to install gas or oil boilers, we have assumed that this will instead go towards heat pumps. However, there is a significant difference in capital cost which would affect the number of installations that could be carried out with the same amount of funding. The upfront capital cost of boilers and heat pumps varies depending on the model selected and the installation/labour requirements; however, as a rough estimate, we have assumed that only ¼ the number of heat pumps could be installed with the same amount of funding, based on current prices.[69])

To estimate the impact of the £200m Green Public Sector Estate Scheme, we referred to evidence from the Climate Change Committee (CCC) on the typical cost of implementing common energy efficiency measures (£/m^2 floor area).[70] We assumed 15% of the fund would go towards administrative costs[71] and estimated the total floor area (m^2) that could be upgraded based on the remaining 85% of funding. Benchmarks for energy use in public buildings (kWh/m^2 per year) were then used to estimate the pre-retrofit fuel consumption

[69] According to the Energy Saving Trust, ASHPs typically cost around £7,000-£13,000 at present. By comparison, the cost of replacing a boiler typically ranges from around £1,600-£3,500. For more information, refer to: https://energysavingtrust.org.uk/advice/air-source-heat-pumps/

[70] CCC, *'The costs and benefits of tighter standards for new buildings'* (2019). Available at: https://www.theccc.org.uk/wp-content/uploads/2019/07/The-costs-and-benefits-of-tighter-standards-for-new-buildings-Currie-Brown-and-AECOM.pdf

[71] Department for Energy Security and Net Zero, *'Sustainable Warmth competition: questions and answers'* (2022). Available at: https://www.gov.uk/government/publications/apply-for-the-sustainable-warmth-competition/sustainable-warmth-competition-questions-and-answers#administrative-costs

(kWh per year) that amount of floorspace would require.[72,73] We then assumed that retrofitting measures would reduce this by 15%, which gave a total estimated saving (kWh per year).[74] Since the majority of non-domestic properties that currently do not have zero direct emission heating systems (ZDEH) instead use mains gas as their main fuel type (61-66%),[75] we assumed that this saving would apply to gas consumption in non-domestic buildings.

Where quantitative information was not available, we have not provided a quantitative estimate of the policy's impact, but instead assumed that the policies will contribute towards bridging the 'gap' to achieving the EPC rating targets.

(b) To estimate the overall impact of upgrading domestic buildings to the target minimum EPC ratings, we have referred to published research on the typical fuel consumption of domestic buildings by EPC rating in England[76] and scaled the data for Scotland based on the current distribution of EPC ratings.[77] This allows us to then re-calculate what the total fuel consumption would be if the distribution of EPC ratings changes, as illustrated below:

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[72] CIBSE Benchmarking tool. Available at: https://www.cibse.org/knowledge-research/knowledge-resources/knowledge-toolbox/benchmarking-registration

[73] Zero Waste Scotland Public Sector Benchmarking Tool. Available at: https://zerowastescotland.org.uk/content/scottish-public-sector-benchmarking-tool

[74] This value was selected based on a review of evidence on the average savings in non-domestic buildings. Note that, unlike domestic buildings, both energy use and the potential energy savings from retrofitting vary widely among the non-domestic stock. Sources include:

- Carbon Trust, *'Building the Future Today'* (2009). Available at: https://www.carbontrust.com/resources/building-the-future-today
- BEIS, *'Consultation on the Non-Domestic Private Rented Sector Minimum Energy Efficiency Standards'* (2020). Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/839362/future-trajectory-non-dom-prs-regulations-consultation.pdf
- Better Buildings Partnership, *'Real Estate Environmental Benchmarks: 2019 Energy Snapshot – Chart 6'* (2020). Available at: https://www.betterbuildingspartnership.co.uk/sites/default/files/media/attachment/BBP_REEB%202019%20Energy%20Snapshot.pdf
- Greater London Authority, *'The London Plan 2021'* (2021). Available at: https://www.london.gov.uk/what-we-do/planning/london-plan/new-london-plan/london-plan-2021
- There are also numerous case study examples of buildings achieving energy savings of 30% or more. See, for example, the Better Buildings Partnership report, *'Helping businesses to improve the way they use energy'* (2018), available at https://www.betterbuildingspartnership.co.uk/sites/default/files/media/attachment/Better%20Buildings%20Partnership%20-%20Call%20for%20evidence%20-%20helping%20businesses%20to%20improve%20the%20way%20they%20use%20energy.pdf

[75] Energy Saving Trust, '*Non-Domestic Analytics* - Version 1.1' (2022). Unpublished.

[76] BEIS, *'Domestic energy consumption by energy efficiency and environmental impact'* (2015). Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/669734/Domestic_Energy_Consumption_by_Energy_Efficiency_and_Environmental_Impact.pdf

[77] Scottish Government, *'Scottish Housing Condition Survey - Table 20: EPC Band by Tenure in 2019'* (2021). Available at: https://www.gov.scot/collections/scottish-house-condition-survey/

Chart: Current EPC ratings by tenure

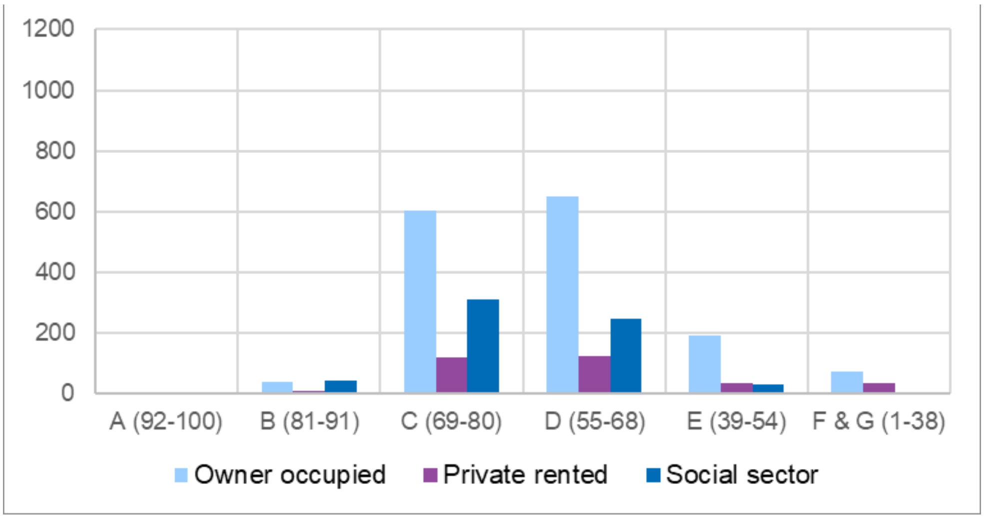
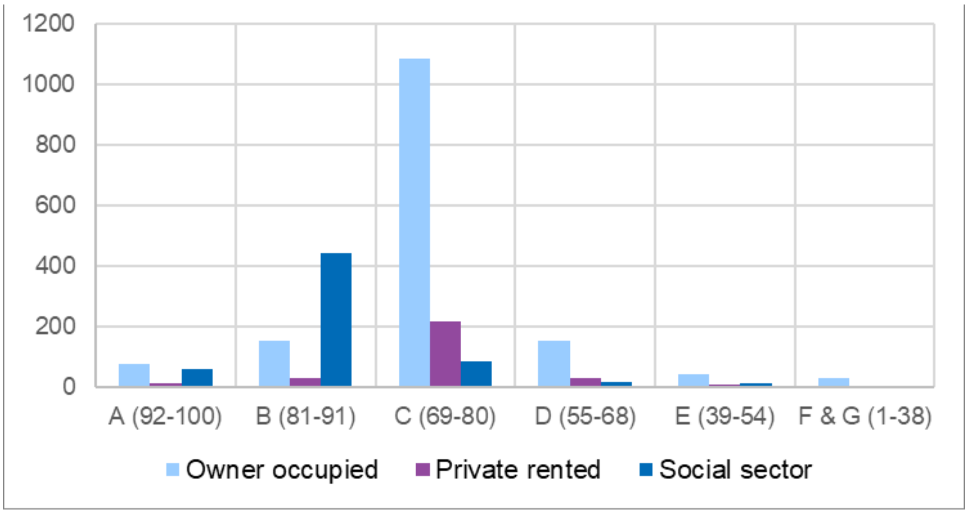


Chart: Future EPC ratings by tenure



Although there are limitations of using scaled data for England, given the significant evidence that shows that EPC ratings alone are not a predictor of actual fuel consumption, this approach was agreed to be suitable following discussions with the Scottish Government.

12.10.2 Replacement of heating systems

As with energy efficiency (see above), we understand that there is an overall target for replacing heating systems, as well as individual policies that will get some of the way towards the target, but that there will be a ‘gap’ between these, pending confirmation of further policies or programmes.

Our approach to modelling the existing policies that address both heating and energy efficiency is described in the previous section. This section sets out our approach to modelling the impact of decarbonising the equivalent of 50,000 non-domestic buildings, introducing the zero direct emission heating (ZDEH) target, and the RHI. These are addressed in turn below.

Non-domestic buildings: To model the impact of decarbonising the equivalent of 50,000 non-domestic buildings, we derived average fossil fuel consumption figures per building based on the total number of non-domestic buildings[78] (c. 230,000) and subtracted this from the total fuel consumption for each building that is decarbonised. The reduction in fossil fuel use will therefore be directly proportional to the number of buildings that are decarbonised. This is a highly simplistic approach, but in the absence of any other details on how this will be achieved or what types of buildings would be targeted, it is considered sufficient for the purpose of this analysis. In the future, this assessment could be refined as part of a later project; it is understood that Scottish Government has recently commissioned a study examining data on non-domestic buildings[79] that was not publicly available at the time of writing.

ZDEH: We have modelled the phase-out of fossil fuel heating systems to take place linearly between the proposed start date of the policy for each sub-sector and the proposed backstop date. However, there is not currently a regulatory approach for achieving this, and furthermore, that the policies are likely to be tied to trigger points,[80] so implementation would not happen linearly.

Assuming most of these buildings will use heat pumps, this has been modelled by reducing the heat demand for buildings based on the relative efficiency of typical gas boilers and heat pumps as follows:

Electricity used for heat = n x (85% / 3.0)

where n is the benchmark for fuel consumption (kWh per year), 85% is the assumed efficiency of a typical gas boiler, and 3.0 is the assumed Seasonal Coefficient of Performance (SCOP) for a typical heat pump.

The assumed 3.0 SCOP for heat pumps is in line with the CCC assumptions made in the 6th Carbon Budget report[81] (SCOP between 2.83 and 3.26). In practice, there will be a mix of ZDEH technologies that are adopted, such as ground and air source heat pumps and heat networks, so this should be understood as a ‘blended’ efficiency factor representing the stock average.

RHI: The RHI measures are only modelled from 2020-2022 due to the closure of the scheme. Note that the amount of publicly available information[82] differs for domestic and non-domestic RHI installations, and the statistics do not report the annual output or year-

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[78] Scottish Government, *‘Energy efficiency in non-domestic buildings’* (n.d.). Available at: https://www.gov.scot/policies/energy-efficiency/energy-efficiency-in-non-domestic-buildings/

[79] ClimateXChange, *‘An evidence review of data associated with non-domestic buildings’* (2022). Available at: https://era.ed.ac.uk/handle/1842/39306

[80] See sections *‘All-Tenure Zero Emissions Heat Standard’* and *‘Regulatory Trigger Points and Area-Based Regulation’* of Scottish Government, *‘Heat in Buildings Strategy’* (2021). Available at: https://www.gov.scot/publications/heat-buildings-strategy-achieving-net-zero-emissions-scotlands-buildings/

[81] CCC, *‘The Sixth Carbon Budget: Buildings sector Summary’* (2020). Available at: https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Buildings.pdf

[82] BEIS, *‘Renewable Heat Incentive Statistics’* (2022). Available at: https://www.gov.uk/government/collections/renewable-heat-incentive-statistics

on-year changes by country. Furthermore, the emissions savings from RHI installations depend heavily on which technology is being installed and, crucially, which fuel is being displaced. These factors make it difficult to provide a reliable assessment of the impact of the RHI, particularly for non-domestic installations, which were therefore excluded from the analysis. To estimate the impact of the domestic RHI, we cross-referenced an Energy Saving Trust (EST) report on renewable heat in Scotland.[83]

The number of domestic RHI installations in Scotland was estimated using statistics on the total number of domestic RHI accreditations in Great Britain over time (RHI Table M2.2) compared with the EST report, which cited figures for 2019. According to the RHI statistics, the vast majority (c. 95%) of installations in the years 2019-2022 were heat pumps, and according to the EST, around 87% of installations in Scotland are in off gas grid areas. On that basis, for simplicity it was assumed that all installations would displace oil (petroleum products) and replace it with a heat pump. Sensitivity testing indicated that this provides total emissions reductions in line with the averages if different fuels are being displaced. Typical system capacities and running hours for domestic heat pumps in Scotland were taken from the EST report.

Other policies: Other policies in this category, such as LHEES and the review of Permitted Development Rights (PDRs), have not been quantified as the Scottish Government has advised that there is no quantitative information / data available on the number and type of measures likely to be required or funded. They are enabling measures but will not necessarily have a direct GHG reduction impact.

12.10.3 Installation of smart meters

We have assumed that all domestic customers will have smart meters by the end of 2025 in line with the scheme targets. Evidence on the scale and longevity of energy savings is mixed[84] although they are relatively small compared to retrofitting measures or switching to heat pumps. For the purpose of this assessment we have assumed that smart meters reduce domestic heating demand by 1% on average. We have assumed that 56% of properties do not yet have a meter operating in smart mode as of 2022, so the savings would only be achieved in these properties.[85]

For non-domestic buildings, there is less data available on:

- the current proportion of fuel that is used to supply heat; and
- the energy savings that can be achieved from installing smart meters.

ECUK statistics suggest that around 56% of fuel consumption in the service sector is used for space heating and hot water, although this is less well-characterised than energy use in the domestic stock due to the greater variation in building types and energy end uses. If

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[83] EST, *'Renewable Heat in Scotland'* (2020). Available at: https://energysavingtrust.org.uk/report/renewable-heat-in-scotland-2020/

[84] BEIS, *'Smart meter rollout cost-benefit analysis'* (2019). Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/831716/smart-meter-roll-out-cost-benefit-analysis-2019.pdf

[85] BEIS, *'Smart Meter Statistics: Quarterly Report to end March 2022'* (2022). Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1077592/Q1_2022_Smart_Meters_Report.pdf

we assume, as for the domestic stock, that there is already some uptake of smart meters, and that these reduce heat demand by around 1%, then smart meters would result in a less than 0.56% reduction in fuel consumption in non-domestic buildings. Because this is a very small impact, and given the uncertainty surrounding this estimate, non-domestic smart meters have not been modelled separately.

12.11 New BUILDINGS

12.11.1 Energy efficiency

Following discussions with Scottish Government, it was agreed not to model the impacts of higher energy efficiency targets in Building Regulations on the basis that these were not confirmed at the time of analysis.

New domestic buildings have been modelled to performance standards in line with recent new builds (where the first year of operation was 2015-2017), which are assumed to have roughly 1/3rd lower heat demand than the stock average.[86] To estimate the scale of new domestic development, we have used the National Records of Scotland (NRS) projections for the number of households as a proxy for the number of dwellings.

In non-domestic buildings, space heating demands typically account for a much lower proportion of the total energy demand (c. 28%) compared with domestic buildings (c. 76%).[87, 88] Therefore, fuel consumption in non-domestic buildings is assumed to be less sensitive to building performance standards. Instead, it has been modelled to scale in line with GVA growth.

12.11.2 Low carbon heating systems

New domestic buildings have been modelled as having zero direct emissions heating (ZDEH) systems from 2024. The modelling approach is the same as for existing buildings (see above) whereby heat consumption is reduced based on the relative efficiencies of boilers and heat pumps.

It is understood that there will be a 3-year transition period for buildings granted planning permission prior to the regulations coming into effect; however, for the purpose of this analysis, all are assumed to be compliant from 2024. The implications for the results are minimal; modelling it this way will have a small impact on cumulative emissions between now and 2045 but no impact on annual emissions in 2045.

See above for an explanation of the underlying growth assumptions and information on non-domestic energy use.

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[86] BEIS, *'Energy consumption in new domestic buildings 2015 to 2017 in England and Wales'* (2019). Available at: https://www.gov.uk/government/statistics/energy-consumption-in-new-domestic-buildings-2015-to-2017-england-and-wales

[87] BEIS, *'Energy Consumption in the UK: End uses data tables'* (2022). Available at: https://www.gov.uk/government/statistics/energy-consumption-in-the-uk-2021

[88] Scottish Energy Statistics Hub, available at: Scottish Energy Statistics Hub (shinyapps.io)

12.12 Miscellaneous

12.12.1 Renewable electricity generation

Information on the number and type of CARES installations was not available during this project, so the impact has not been assessed.

Note: In principle, any targets aimed at improving EPC ratings could stimulate uptake of small-scale renewable electricity technologies, but our review of policies suggests that the aim of improving EPC ratings is generally more aimed at reducing bills and/or improving energy efficiency.

12.12.2 District Heat Networks (DHNs)

Scottish Government has advised that detailed quantitative information is not yet available on the number and types of DHN schemes likely to be delivered by these policies/programmes. Per correspondence with Scottish Government via email 19 August 2022, we agreed to provide off-model estimates of (a) the Heat Networks (Scotland) Act targets being met and (b) the District Heating Loan Fund (DHLF).

The Bute House Agreement increased the HIBS Social Housing Decarbonisation funding from £1.6bn to £1.8bn, and that includes £300m for Scotland's Heat Network Fund (HNF).[89] This will form the basis for our assessment. We have reviewed the existing impact assessment for the DHLF[90] and separate BEIS research on the typical cost of heat networks[91] to estimate the number of projects and/or MWh of heat output that this could fund.

We have assumed that this contributes to the overall targets being met (2.6 TWh of output by 2027 and 6 TWh of output by 2030).

Estimating impacts of DHNs

Heat networks offer the potential to deliver GHG emissions reductions in several ways, examples of which include:

- Providing an opportunity to utilise waste heat - e.g., from waste treatment or other industrial processes
- Plant may operate more efficiently when there is a high and consistent heat load (although note that in some circumstances this may be offset by heat loss along the distribution network)

From a logistical standpoint, they can also facilitate the transition to lower emission heat sources, because if buildings are connected to a communal or district heat supply, then in

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[89] Scottish Government, *'Heat Networks Delivery Plan'* (2022). Available at: https://www.gov.scot/publications/heat-networks-delivery-plan/

[90] Energy Saving Trust '*Evaluation of the District Heating Loan Fund (DHLF)*' (n.d.). Available at: https://energysavingtrust.org.uk/programme/district-heating-loan-fund/

[91] DECC, *'Assessment of the costs, performance and characteristics of UK heat networks'* (2015). Available at: https://www.gov.uk/government/publications/assessment-of-the-costs-performance-and-characteristics-of-uk-heat-networks

principle it may be possible to switch one centralised system to a low or zero carbon heat source, which could be easier than replacing individual heating systems.

However, the actual energy and emissions impacts depend heavily on multiple factors. From a GHG emissions standpoint, one of the key questions is what heating systems and fuel types are currently in use, and what they are being replaced by. Furthermore, heat networks or communal heating systems may be installed in new developments, in which case there may be no impact at all on existing sources of GHG emissions, and instead the effects might be captured under the New Build Heat Standard (NBHS) for new buildings.

It is understood that, although the Scottish Government has set targets for the amount of heat (in TWh) that will be supplied by heat networks in future, there is currently no detail on exactly what types of heat networks would be delivered, which makes a detailed assessment impossible.

These issues notwithstanding, to provide some general context for the potential impact of this target (and the available funding that has been allocated towards it), we have provided some high-level estimates below. These are based on calculations described in Appendix 3.

Because it is unclear what sector the heat networks would supply (or where any waste heat might come from) the following rough calculations have been provided separate to the main GHG projections model.

1. Potential impact of achieving the target of 6 TWh of output by 2030:

For the purpose of this assessment we have assumed that all of the heat networks displace natural gas, as this is the most common fuel used for space heating in Scotland. Based on the emission factors used, using 6 TWh of natural gas per year would result in approximately 1,200 ktCO_2e per year. This is equivalent to the GHG reduction that would theoretically be achieved if this was replaced with a zero direct emission heat source (such as large-scale heat pumps supplied with 100% renewable electricity). For context, that is roughly 3% of Scotland's 2020 GHG emissions of 39,950 ktCO_2e.[92]

2. Potential contribution of the £300m Heat Network Fund towards the overall target

As previously explained, we have assumed that £300m will be made available as part of Scotland's Heat Network Fund (HNF) following the Heat Networks Delivery Plan (HNDP).

The existing evaluation for the District Heating Loan Fund (DHLF)[93] indicates that the range of costs for different schemes was £100k/scheme to £400k/scheme. On that basis, £300m could help to support between 750 and 2,700 heat network projects. It is important to note that historically, almost all of these were fuelled by biomass. Going forward, it may be more realistic to assume that heat networks would be supplied by heat pumps due to

[92] Scottish Government, *'Scottish Greenhouse Gas Statistics 2020'* (2022). Available at: https://www.gov.scot/publications/scottish-greenhouse-gas-statistics-2020/

[93] Energy Saving Trust '*Evaluation of the District Heating Loan Fund (DHLF)*' (n.d.). Available at: https://energysavingtrust.org.uk/programme/district-heating-loan-fund/

concerns about air quality, the availability of sustainably sourced biomass, and lifecycle GHG emissions.

For the reasons set out above, it is difficult to provide an estimate of the GHG emissions impact of individual heat network schemes. Therefore, to estimate the potential impact this could have relative to the target of 6 TWh of heat being supplied by heat networks by 2030, we have reviewed Department of Energy & Climate Change (DECC) research on the typical capital costs of heat networks.[94] The research (which, it should be noted, is based on a limited selection of case studies) indicates that there is considerable variability in the capital cost of schemes – anywhere in the region of £250/MWh to over £900/MWh (see Figure 2 of the aforementioned DECC report). Purely on that basis, as a very rough estimate, the £300m in funding could potentially help to deliver heat networks with an output of between 0.33 and 1.2 TWh, which is equivalent to 6% to 20% of the overall 6 TWh target.

Again, note that the type of heat network is important, and this estimate does not reflect differences in prices between heat pumps and other types of systems like biomass- or gas-fired CHP.

Concluding points relating to heat networks

Based on the above assumptions, we estimate that achieving the 6 TWh target would reduce emissions by around 3% compared with a 2020 baseline of 40 $MtCO_2e$. The £300m in heat network loan funding could potentially contribute towards up to 20% of that target being met, leading to emissions reductions that are roughly equivalent to 0.2%-0.6% of total territorial emissions in 2020. This is likely to be an overestimate because it assumes that the heat networks will all use a zero direct emissions heat source. However, there is a much broader set of policies that will help to support and enable the development of heat networks in Scotland which have not been quantified.

These estimates are intended only to provide general context for the potential scale and direction of impacts from these policies, on the assumption that more detailed assessments would need to be carried out in future.

[94] DECC, *'Assessment of the costs, performance and characteristics of UK heat networks'* (2015). Available at: https://www.gov.uk/government/publications/assessment-of-the-costs-performance-and-characteristics-of-uk-heat-networks

Scottish Government
Riaghaltas na h-Alba

This publication is available at **www.gov.scot**

Any enquiries regarding this publication should be sent to us at

The Scottish Government
St Andrew's House
Edinburgh
EH1 3DG

ISBN: 978-1-83521-855-6 (web only)

Published by The Scottish Government, January 2024

Produced for The Scottish Government by APS Group Scotland, 21 Tennant Street, Edinburgh EH6 5NA
PPDAS1402234 (01/24)