Quantifying the implications of the Paris Agreement:

What role for Scotland?

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Quantifying the implications of the Paris Agreement: what role for Scotland?

KEY MESSAGES

1) Scotland will exceed its Paris 2°C commitment in under 10 years at current CO_2 levels[1]

Combining the Paris equity criteria with the small and rapidly dwindling global carbon budget for 2°C leaves Scotland facing a profound mitigation challenge. For Scotland to make its minimum 'fair' contribution to the Paris "well below 2°C" commitment, its post-2017 energy-only carbon budgets should be between 229 and 394 $MtCO_2$, or approximately six to nine years of current Scottish energy-only CO_2 emissions.

2) Scotland needs to deliver CO_2 mitigation of, at least, 10% each year – starting in 2018

Assuming a highly optimistic mitigation agenda is actioned by the global community, then for Scotland to deliver on its 2°C commitment it needs to begin an immediate programme of mitigation at a minimum average rate of 10% p.a. in absolute emissions. Any delay in starting, or in pursuing a rate below 10% p.a., will either contribute to the failure of Paris or require still more fundamental mitigation in the early 2020s.

3) Scotland needs to eliminate all its industrial process-CO_2 emissions prior to 2050

Scotland must join other wealthy nations in leading the mitigation agenda on industrial process emissions – particularly from cement production. Moreover, Scotland needs to work closely with poorer and industrialising nations to reduce and rapidly eliminate their cement emissions.

4) Scotland needs to begin a programme of rapid reforestation & land-management

Carbon emissions from Scotland's 'land use, land use change and forestry' (LULUCF) should be managed to ensure that, from 2018-2100, the net level of sequestration is equivalent to both Scotland's early LULUCF emissions and longer-term non-CO2 emissions. Moreover, the management of LULUCF should include action to increase wider social and environmental benefits (i.e. improve natural capital).

5) Scotland's non-CO_2 emissions need to reduce by around 3% each year – starting now

The lower reduction rate for non-CO_2 emissions (c.f. CO_2-only) relates to there being an 'emissions-floor' beyond which non-CO_2 emissions from agriculture are unlikely to be reduced, at least by 2050.

6) Scotland needs to begin an urgent and phased closure of its oil and gas sector

The Paris Agreement's steer on equity requires wealthy and industrialised nations to lead the way on early and deep mitigation. Given that for 2°C between 70 and 80% of known fossil fuel reserves cannot be exploited (1) (higher still for 1.5°C) and that Scotland is a wealthy industrial nation with excellent prospects for renewable energy, the Scottish Government needs urgently to enact policies to rapidly cease hydrocarbon production from its oil and gas sector. This conclusion remains valid even when considering the prospect of carbon capture and storage (CCS). First, the limitations on deployment rates of this still fledgling technology (when applied to power stations) mean that it can have no significant role to play in the 2°C timeframe for full decarbonisation required of industrialised

[1] The carbon budgets of OECD nations are highly sensitive to the mitigation agenda of the non-OECD nations. The conclusion here assumes an aggregate peak in non-OECD emissions occurring between 2022 and 2023, with 10% mitigation each year by 2045 and over 95% cut in emissions (c.f. 2015) by the early 2060s. By any reading this is a highly ambitious agenda, well beyond anything previously countenanced for the non-OECD nations.

nations. Second, whilst the 'capture' element of CCS may yet be significantly improved, the high levels of emissions associated with upstream fossil fuel production put the life-cycle emissions of CCS at 100-200gCO_2/kWh far beyond what would be necessary for it to have any major role in power generation (2). However, CCS is very likely to make a significant contribution to decarbonising the process emissions from cement and steel production particularly as well those arising from other large industrial activities.

This report translates the temperature and equity commitments enshrined in the Paris Agreement into a range of post-2017 carbon budgets for Scotland. To appropriately understand and contextualise the conclusions of this section, it is important to be cognisant of the principal assumptions underpinning the analysis:

1) A very conservative reading of the Paris commitments; consequently the conclusions should be understood as erring towards a highly optimistic range of carbon budgets and a minimum level of mitigation.
2) All other major emitters will make their respective contribution to reducing emissions in line with, as a minimum, a similar reading of the Paris commitments (i.e. there are no significant 'free riders').
3) No 'negative emission technologies' (NETs) are used to extend the carbon budget ranges (i.e. to make the mitigation challenge less onerous).
4) No carbon cycle feedbacks, outside those included in the model runs underpinning the IPCCs carbon budgets, are included, e.g. the carbon budgets are not reduced through issues such as methane emissions from melting permafrost or additional soil metabolism as temperatures rise.
5) Emissions of carbon dioxide from deforestation are, across the century, matched by carbon sequestration through progressive 'land use' and 'land-use change and forestry' (LULUCF).
6) Emissions from international aviation and shipping are included in Scotland's carbon budgets, and are already included in the commitments enshrined in the current Scottish Climate Act. We recommend reviewing whether bunker fuel sales are an adequate proxy for Scotland's ship-sector emissions, or whether a trade-based assessment would be more appropriate.

1.0 What carbon budgets for Scotland (for a fair contribution of a "likely" chance of 2°C)?

The Climate Change (Scotland) Act 2009 has set a target of a reduction of at least 80 percent in greenhouse gas (GHG) emissions by 2050 from 1990 levels along with an interim target of at least 42% reduction by 2020[2]. By 2015 Scotland had achieved a 41% reduction in GHG emissions compared to 1990 (3). However, using a consumption-based[3] accounting method little, if any, real reduction has been achieved in Scotland's total contribution to global emissions. The Scottish Carbon Footprint analysis shows that the consumption-based emissions for 2013 were 1% higher than in 2000; at the same time territorial-based emissions have reduced by 29% (4). Whilst Scotland may meet its territorial emissions reduction target for 2020, further ambitious decarbonisation, and attention to the embedded carbon in imports, is essential if it is to deliver its fair contribution to the Paris Agreement goal of "well below" 2°C.

The future CO_2 only targets and emissions budget for Scotland consistent with a "likely" chance of avoiding 2°C based on a territorial framework are estimated as shown below. The non-CO_2 emissions target is estimated separately based on a 2050 non-CO_2 'emissions floor'[4] and assumptions on Scotland's fair contribution to that emissions floor.

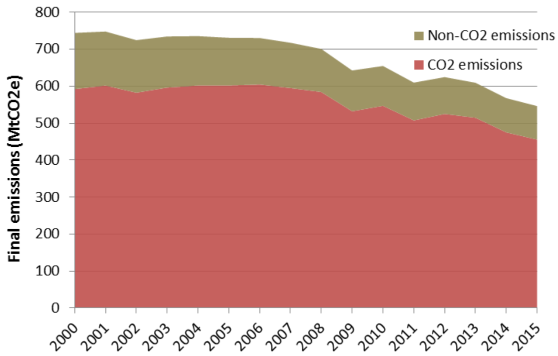
2.0 Translating the 2°C objective to a fair carbon budget range for Scotland

The development of post-2017 carbon budget ranges and carbon emissions pathways for Scotland builds on detailed research transposing the Paris 2°C temperature and equity commitments to the level of the UK. Following the method of Anderson and Bows (5), the global carbon budgets published in the IPCC AR5 synthesis report (6) are taken as a starting point. A deduction is made as a "global overhead" for process emissions arising from cement production (100 $GtCO_2$) (7). An energy-only post- 2017 carbon budget range is then developed for the non-OECD nations, leaving a remaining budget range for the richer OECD countries[5]. The non-OECD range relates to six scenarios based on assumptions about how quickly non-OECD countries may peak and subsequently mitigate their emissions, as detailed by Anderson and Broderick (8). This approach of considering the non-OECD nations first is guided by the stipulation of equity within the Paris Agreement (and its earlier forebears, from Kyoto onwards). The remaining OECD budget is then apportioned to the UK to provide a national carbon budget range. The apportionment regimes applied are population and "grandfathering" of recent emissions (both are averaged for the period 2010 to 2015). The UK budgets are subsequently apportioned to Scotland based on population, grandfathering and Gross Domestic Product (GDP), with illustrative emission pathways developed to be in line with these budgets. The proposed budgets and pathways provide a sufficiently broad envelope of outcomes to inform the 'recommended carbon pathway' for Scotland.

The CO_2 emissions in this analysis include international aviation emissions based on bunker fuel for both Scotland (3) and the UK (9). International shipping emissions for the UK estimated by BEIS

[2] Includes international aviation and shipping on a bunker basis
[3] Emissions associated with the spending of Scottish residents on goods and services together with emissions directly generated by Scottish households, through private heating and motoring
[4] It is often argued that it may not be technically, economically or politically feasible to eliminate non-CO_2 emissions (for example preserving global food security) and this minimum limit is referred to as an 'emissions floor'.
[5] The OECD non-OECD classification is widely understood and is sufficiently close to both "non-Annex 1" and "non-Annex B" climate policy groupings to be comparable.

(based on bunker fuels) underestimate actual emissions as ships are typically fuelled elsewhere on route (10). Walsh et al (11) indicates an underestimate of 52% in 2015 and 55% in 2012 for the UK international shipping emissions. The revised shipping emissions data for the UK (based on Walsh et al (11)) is used in this analysis. Process emissions arising from cement production along with Land use, land-use change and forestry (LULUCF) for the UK and Scotland national inventories are excluded in this analysis as (borrowing from the aforementioned UK analysis) they have been allocated as a global overhead. The revised UK and Scotland GHG (and CO_2) emissions from 2000 to 2015 are shown in Figure 1 and Figure 2.



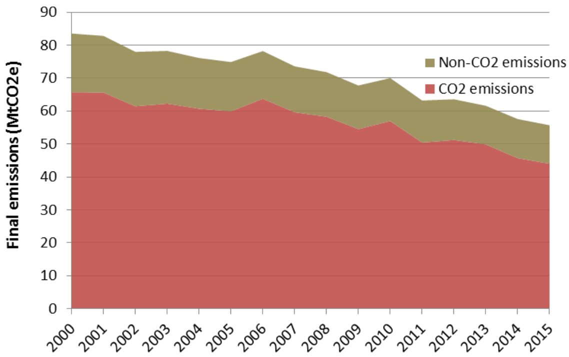


Figure 1 (left): Final UK Greenhouse Gas emissions including international aviation and shipping but excluding LULUCF and cement process emissions (energy only). **Figure 2 (right)**: Final Scotland Greenhouse Gas emissions including international aviation and shipping but excluding LULUCF and cement process emissions (energy only).

This analysis is based on territorial accounting, and does not take account of Scotland's emissions associated with its imports and exports. Non-CO_2 emissions cannot be incorporated with CO_2 in a cumulative emission budget because of their different temporal effects on the climate.

2.1 Apportioning the UK budgets to Scotland

Three apportionment regimes are used here to allocate the UK ("well below 2°C) energy-only CO_2 emissions budget (post-2017) to Scotland. These are outlined below and provide a sufficiently broad envelope of budgets to cover the outcomes from most apportionment regimes.

Grandfathering (GF) – In this regime carbon budget for Scotland is estimated on the basis of recent emissions (mean from 2010-2015). Emissions from Scotland are compared to those of the UK from 2010 to 2015. The emissions budget (2018-2100) for Scotland is then apportioned from the UK budget based on its average proportion of final CO_2 emissions for the period 2010-2015.

Population (Pop) – The UK population (12) is compared to that of Scotland (13) from 2010 to 2015. The emissions budget (2018-2100) for Scotland is then apportioned from the UK budget based on its average proportion of population for the period 2010-2015.

Gross domestic product (GDP) – The UK GDP[6] (14) is compared to that of Scotland (15) from 2010 to 2015. The emissions budget (2018-2100) for Scotland is then apportioned from the UK budget based on its average proportion of GDP for the period 2010-2015.

Based on these apportionment regimes, the subsequent CO_2 emission budgets, illustrative mitigation rates and pathways are provided in Table 1 and Figure 3.

[6] GDP at market prices, current price seasonally adjusted (£m)

Table 1: Apportionment regime[7], CO_2 budgets and annual mitigation rates for Scotland, 2018-2100

Apportionment regime *(bracket term is Scotland's proportion of the UK)*	**UK mid-value budget[8] ($MtCO_2$)**	**Scotland mid value budget ($MtCO_2$)**	**Average annual mitigation rate (%)**
Grandfathered to Scotland from UK *UK CO_2 based on population split of OECD* **GF-Pop-** (9.8%)	4000	394	9.4%
Population split to Scotland from UK *UK CO_2 based on population split of OECD* **Pop-Pop** (8.3%)	4000	333	10.9%
GDP[9] split to Scotland from UK *UK CO_2 based on population split of OECD* **GDP-Pop** (7.9%)	4000	317	11.4%
Grandfathered to Scotland from UK *UK CO_2 grandfathered from OECD* **GF-GF** (9.8%)	2887	284	12.6%
Population split to Scotland from UK *UK CO_2 grandfathered from OECD* **Pop-GF** (8.3%)	2887	240	14.5%
GDP split to Scotland from UK *UK CO_2 grandfathered from OECD* **GDP-GF** (7.9%)	2887	229	15.2%

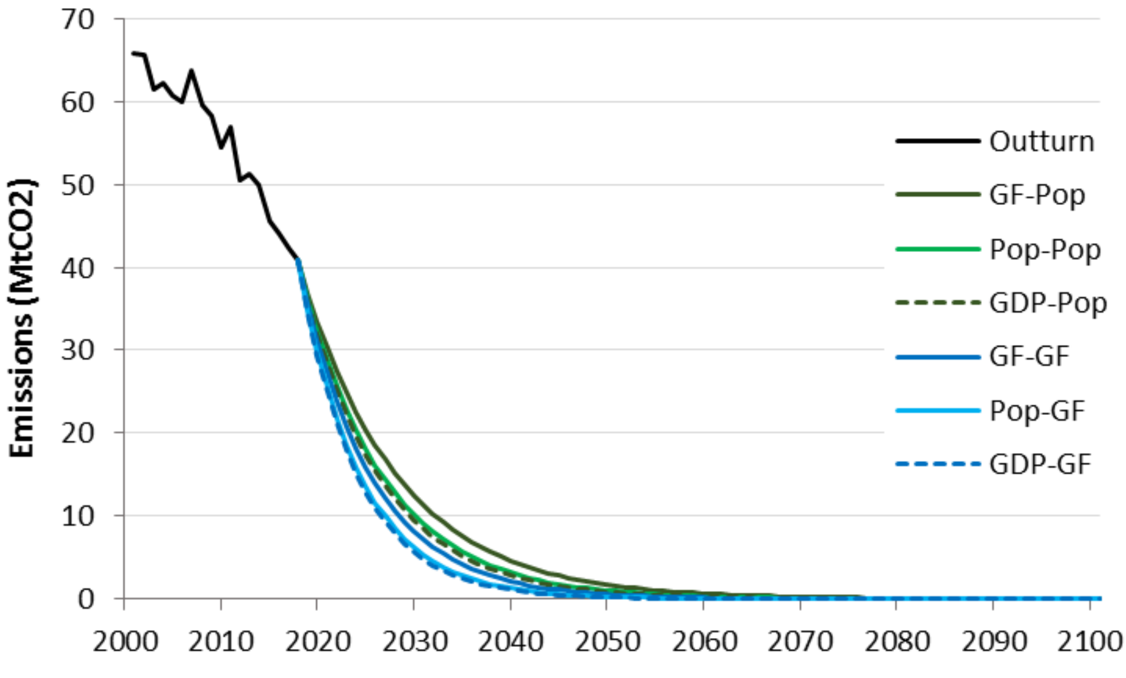


Figure 3: Fossil fuel CO_2 only emissions pathways for Scotland.

[7] The UK mid-value budgets used here are taken from the report "Quantifying the implications of the Paris Agreement: what role for the UK's energy system?" Op cit 2.
[8] Assumes a peak in non-OECD emissions between 2022 and 2023 (detailed analysis and the methodology underpinning this are in the accompanying report: "Quantifying the implications of the Paris Agreement: what role for the UK's energy system?").
[9] Using GDP as a proxy for apportioning the UK emissions to Scotland ignores the fact that its GDP/capita income is ~5% lower than that for the UK as a whole. However, according to the Scottish Government (27), when applying a purchasing power parity (PPP) index, Scottish citizens have an income 2.6% above the UK average. These small differences in income have little impact in determining Scotland's carbon budget; with GDP/capita increasing the value by between 15 and 30 $MtCO_2$, whilst PPP/capita reduces it by around half of this range. Given these small changes, no allowance is made here for differences between Scotland and the UK's GDP and PPP per capita values.

The emissions budgets recommended are substantially smaller than those proposed by the UK Committee on Climate Change and adopted by successive UK and Scottish governments. An abridged critique of the UKCCC budgets is provided in Appendix 1

2.2 Allocating a carbon budget for the LULUCF sector

The Land Use, Land Use Change and Forestry (LULUCF) consist of both emissions and removals of CO_2 from land and forests. Compared to the various energy sectors LULUCF is unusual in that it measures not just carbon releases (e.g. deforestation), but also carbon removals (e.g. carbon uptake in soils, plant growth etc.). The UK's uncertainty range for LULUCF in 2015 is estimated as $\pm$86%, whereas for fossil fuels (energy sectors) it is within the range of $\pm$5%, both with a 95% confidence interval. The LULUCF uncertainties are exacerbated by further reservations over other non-CO_2 GHGs. The main uncertainties arise both from natural variability in vegetation and soils (changes in soil carbon density), and incomplete knowledge about the extent of activities and the underlying processes affecting sinks and sources (16).

The current woodland cover in Scotland is about 18% (74% coniferous and 26% broadleaf tree species), the highest level in the last 3000 years. The woodland cover during pre- industrial revolution was about 4% (17). The Scottish Government's Climate Change Plan (18), proposes specific targets for future woodland expansion to cover 21% by 2032. Scotland's CO_2-only emissions from LULUCF in 2015 were net negative (as were those for England) and estimated at around -7.1MtCO_2, or around 16% of Scotland's total CO_2 emissions (19). Building on this we propose a separate Scottish budget for LULUCF CO_2-only emissions that is tracked separately to, but aligned with, the Scottish energy only carbon budgets.

The carbon budgeting method for Scotland's LULUCF sector has been developed to ensure that across the century any non-CO_2 emissions from 2018-2100 will, at least in part, be compensated by carbon sequestration for the same period. The LULUCF emissions from 2015 to 2050 are based on the 'Stretch' scenario developed by Centre for Ecology & Hydrology (CEH) which assumes an ambitious climate change mitigation programme exceeding current policy aspirations or funding (19). After 2050, the sector continues to provide a stable level of annual sequestration (-6.8 MtCO_2) across the century.

In our proposal, Scotland's LULUCF cumulative emission sequestration from 2018 onwards is approximately equivalent to Scotland's non-CO_2 cumulative emissions for the same period and estimated using our non-CO2 emissions scenario #4 (20) explained in section 3. This approach is illustrated graphically in Figure 4; where the cumulative non-CO2 emissions from 2018 to 2100 (area A) is broadly matched by the LULUCF carbon sequestration (area B), extrapolated from the CEH 'Stretch' scenario.

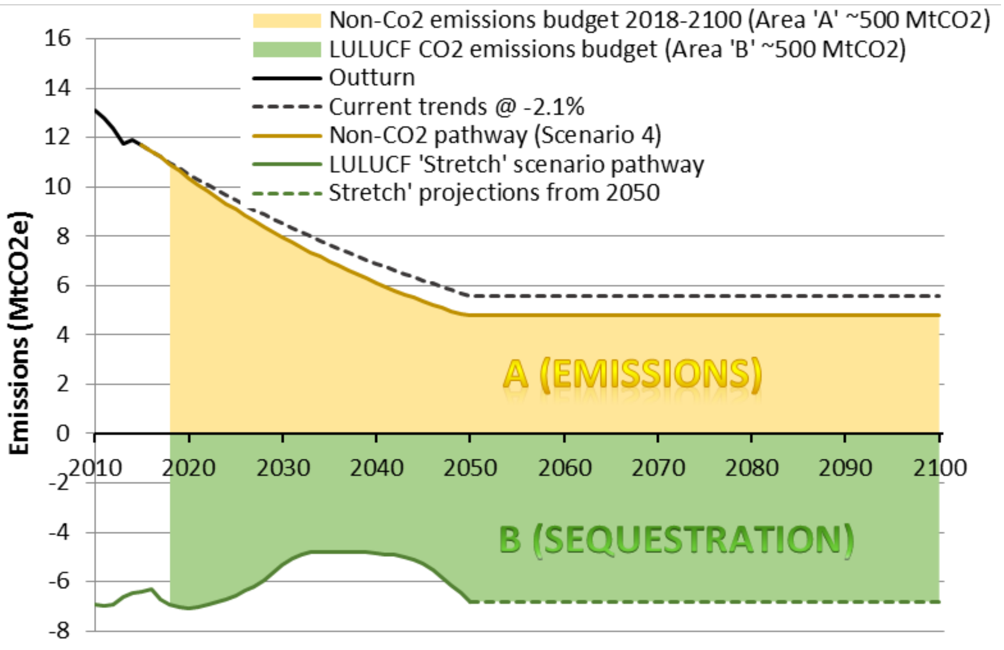


Figure 4: Cumulative emissions budget for the LULUCF sector within Scotland Note: the rate of non-CO2 reduction between 2018 and 2050 exceeds the mean rate Scotland achieved between 2010 to 2015 (i.e. 2.1% p.a.).

2.2.1 Additional information on the Stretch Scenario:

The early decrease in the Stretch scenario sequestration is due to a large number of trees being thinned, or reaching maturity (some 35-50 years since planting) and hence being harvested, alongside a historically low planting rate in the 1990s and 2000s.

The annual area of Scotland's reforestation and afforestation increases from 7.6 kha in 2015 to 15 kha by 2021, and continues at that higher rate until 2050 (see Table 2). Beyond 2050 the level of carbon sequestration is assumed to remain constant. This is achieved through a balance of some ongoing forest restoration, reforestation and afforestation, along with sustainable levels of harvesting timber for uses where the carbon will be securely locked away (for example appropriately designed house building and construction), with any harvested land subsequently replanted. Hence by 2100, total forestland would be around 2656 kha.

It is worth noting that Scotland's LULUCF emissions are primarily CO_2 and arise principally from forestry. N_2O emissions from forest fertilisation, forest drainage, soil mineralisation and biomass burning are not insignificant. However they, along with small levels of methane (CH_4) emissions arising from biomass burning, are captured in Scotland's non-CO_2 emissions inventory. These sources of emissions will need to be considered carefully in any future forest restoration, reforestation and afforestation programmes.

Table 2: CEH 'Stretch' scenario of Land use area 2014-2050 for Scotland; (kha)

	2014	2030	2050
Forestland	1410	1613	1906
Cropland	589	589	589
Grassland	5598	5333	5032
Wetland	92	92	92
Settlement	199	197	191

3 Non-CO_2 emissions for Scotland

Non-CO_2 emissions contributed 25% of the Scotland's GHGs in 2015. Methane (CH_4) and Nitrous Oxide (N_2O) accounted for 22% of the GHGs whereas Fluorinated gases contributed 3% (Figure 5). An 'emission budget' approach is not used in this analysis as the physical or chemical properties of each GHGs vary with different life times causing the warming in different ways. Furthermore there are large uncertainties in non-CO_2 emissions accounting, as well as challenges in reducing annual emissions below a certain 'emissions floor'. Hence scenarios for delivering given end point targets are developed for non-CO_2 emissions with pathways leading from 2015 to 2050.

Anderson and Bows (20) postulate a global non-CO_2 'emissions floor' of 7.5 $GtCO_2e$ in 2050 assuming a global population of 9 billion (thereafter remaining stable) and the UK Committee on Climate Change (CCC) (21) suggests 6 $GtCO_2e$. While these studies do not reflect on how such reductions could be best achieved, Bows-Larkin et al (22) suggest it is difficult to envisage an absolute fall in non-CO_2 emissions below an 'emissions floor' of around 7 $GtCO_2e$ (by 2050) as a consequence of continued growth in global N_2O emissions. This increase in N_2O is linked to increased absolute fertiliser use deemed necessary to increase yields and thereby improve global food security. Maintaining such a significant emissions floor, increasingly dominated by N_2O, has implications for the rate and level of mitigation required of CO_2 and CH_4 if the Paris temperature commitments are to remain viable (22).

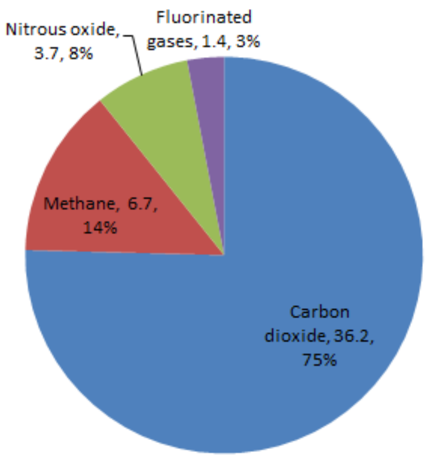


Figure 5: Breakdown of Scottish GHG emissions in 2015 by gas (values in $MtCO_2e$)

Scotland emits 12.5% of the UK's non-CO_2 emissions, which represent ~25% of Scotland's total greenhouse gas emissions (2010-2015) using CO_2 equivalent with a time horizon of 100 years.

The scenarios adopted to estimate Scotland's non-CO_2 end point emissions target for 2050 (as part of the global emissions floor) are outlined below, with the values provided and compared in Table 3. The scenarios assume that post 2050, annual non-CO_2 emissions will remain unchanged (i.e. at the level of the emissions floor).

Scenario 1
The CCC (23) recommend for the UK's 2050 non-CO_2 emissions to be 55 $MtCO_2e$ for meeting UK's 2050 target; this is subsequently grandfathered to Scotland giving a 2050 non-CO_2 emissions value.

Scenario 2
As Scenario 1 but is subsequently apportioned to Scotland on a per capita basis (using UK (24) and Scottish population projections for 2050 (25)).

Scenario 3
Assuming the CCC's global non-CO_2 emissions floor of 6 $GtCO_2e$ by 2050 (21) and with a global population estimate of 9 billion, emissions are allocated to Scotland on a per capita basis (using Scottish population projections (25)).

Scenario 4
Assuming Anderson and Bows global non-CO_2 emissions floor of 7.5 $GtCO_2e$ by 2050 (20) and with a global population estimate of 9 billion, emissions are allocated to Scotland on a per capita basis (using Scottish population projections (25)).

The 2050 end point targets for the above four scenarios are provided in Table 3.

Table 3: End point targets and annual mitigation rates for non-CO_2 emissions for Scotland

Apportion regime	Scotland's non-CO_2 emissions by 2050 ($MtCO_{2e}$)	Annual mitigation rate (%)
Scenario 1	6.9	1.5%
Scenario 2	4.1	3.0%
Scenario 3	3.8	3.2%
Scenario 4	4.8	2.6%

Emission pathways to deliver these end-points are plotted in Figure 6; including an extrapolation of recent data where annual emissions have been reducing at 2.3% (2010-2015).

We recommend the LULUCF pathway shown in Figure 4 should be adopted so as to include sequestration equivalent to area B in order to help compensate for cumulative non-CO_2 emissions from scenario 4 within the Scottish boundary.

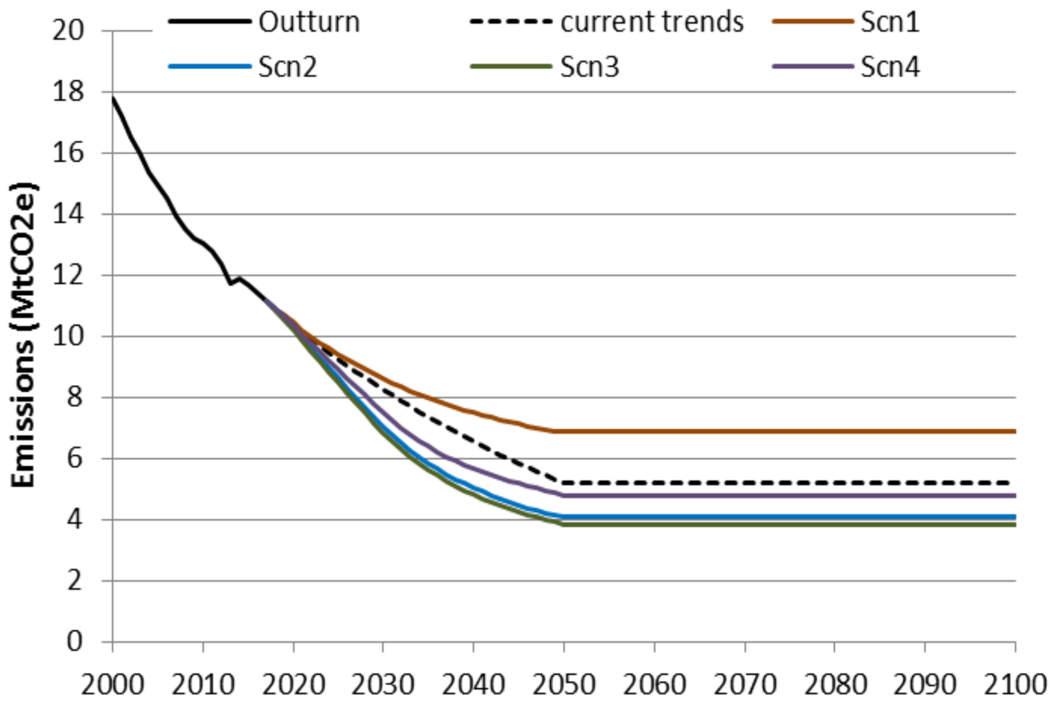


Figure 6: Non-CO_2 emissions pathways for Scotland to 2050

4 Conclusion

The energy-only UK CO_2 emissions budgets are apportioned to Scotland based on three regimes of Grandfathering, Population and GDP. Simple emission pathways corresponding to these three budgets are then derived. A separate Scottish LULUCF CO_2-only emissions budget of approximately 500 $MtCO_2$ from 2018 to 2100 is also provided. The pathways suggest that if Scotland is to make its 'fair' contribution to delivering on the Paris 2°C temperature commitment then it needs to begin an immediate and rapid programme of decarbonisation to remain within the necessary carbon budget range of 229 to 394$MtCO_2$ (for the period from 2018 onwards). To give a sense of the scale of the challenge, at current (2015) CO_2 emission levels[10], Scotland will use its entire budget within 5 to 9 years. Even the 2016 closure of Scotland's large coal-fired Longannet powerstation, and assuming other emissions remaining unchanged, the timeframe is extended by around two years).

To provide a smooth transition in line with the above budgets, average annual mitigation rates of CO_2 from energy need to be between 9% and 15% – beginning in 2018. Some of the annual mitigation rates for Scotland are slightly higher than those for the UK as a whole; this is because Scotland starts from higher per capita emissions (8.2 tCO_2, compared with the 7.0 tCO_2 for the UK[11]). The percentage reduction of emissions for the years 2020, 2030, 2040 and 2050 under each of the scenarios compared to 2015 are shown in Table 4. Any reduction in the mitigation rate in the early years will require a significant increase in the rate in future years for the same budget to be met.

[10] Based on Scotland's 2015 CO_2 emissions (includes international aviation & shipping, but exclude both cement process emissions and from LULUCF).
[11] These values are for 2015 and include international aviation and shipping emissions, but exclude both process CO_2 emissions from cement production and those from LULUCF.

Table 4: Percentage reduction of emissions for the scenarios out to 2050 in relation to 2015

	CO_2-only scenarios						**Non-CO_2 scenarios**				
	GF-Pop	**Pop-Pop**	**GDP-Pop**	**GF-GF**	**Pop-GF**	**GDP-GF**	**current trends**	**Scn1**	**Scn2**	**Scn3**	**Scn4**
2020	31%	34%	35%	38%	42%	43%	10%	9%	13%	13%	11%
2030	74%	79%	81%	84%	88%	89%	27%	23%	35%	37%	32%
2040	90%	94%	94%	96%	97%	98%	41%	33%	52%	55%	48%
2050	96%	98%	98%	99%	99%	100%	52%	41%	65%	67%	59%

Whilst this conclusion is premised on territorial emissions, to abide by the spirit of the Paris Agreement, Scotland's programme of mitigation also needs to be informed by its consumption-based emissions. In addition, as a wealthy, highly educated nation with one of the most promising renewable energy potentials, Scotland needs to demonstrate clear leadership by initiating the early and rapid phase-out of its remaining oil and gas industry – well before the natural exhaustion of resources. As previously noted, the 2°C carbon budget requires that over 70% of known global fossil fuel reserves must remain untapped (1). This proportion would be considerably higher if the 'negative emission technologies' assumed by McGlade and Ekins (1) do not come to fruition, and higher still if the 1.5°C commitment is to have any meaning. Furthermore, the emissions budgets suggests carbon capture and storage (CCS) has no significant role to play due to high levels of life-cycle emissions associated with upstream fossil fuel production at 100-200gCO_2/kWh. However, CCS can make a significant contribution to decarbonisation of industry by capturing CO_2 from process or flue gas streams from four sectors: cement, chemicals, iron and steel and refineries (26).

Turning to the non-CO_2 emissions, these contribute 25% of Scotland's total GHG emissions, with more than half being methane (CH_4). Using an 'emissions floor' approach, non-CO_2 emissions need to reduce annually by between 1.5% and 3.2% out to 2050, after which they will be at their fair proportion of the global emissions floor. Whilst these reduction rates are broadly compatible with current rates, it is very likely that maintaining such rates will be difficult in a changing climate and with lower N_2O emissions (i.e. fertiliser inputs). Consequently, if food security is to be sustained, or even improved, it is essential to develop a programme for mitigating CH_4 emissions that is, at the very least, consistent with the non-CO_2 end point target range of 3.8 to 6.9 MtCO_{2e}; this will give greater scope for nitrogen-based inputs (natural or synthetic). The ongoing 2018-2100 warming from Scotland's non-CO_2 emissions should be compensated by CO_2 sequestered by the country's LULUCF sector.

Finally, and in order to compare the results with the Scottish Government's Climate Change Plan (18), the mean value of CO_2 pathways, LULUCF and non-CO_2 emissions are summed and overall emissions reduction targets are estimated (Table 5). However, whilst combining such different sources and gases may provide a simple political target, we strongly oppose such an approach as it neglects significant differences in both the chemistry and lifetime of the various greenhouse gases. There is a very real risk that a single metric, combining different gases could lead to inappropriate policy responses.

Table 5: Overall greenhouse gas emissions reduction targets for Scotland out to 2050 in relation to 1990

2020	2030	2040	2050
60%	87%	95%	102%

In summary, if Scotland is not to renege on its 2°C Paris commitments, it needs to initiate an immediate, rapid and deep reduction in its annual energy-only carbon dioxide emissions of, at the very least, 10% p.a. At the same time Scotland must maintain ongoing progress in reducing its non-CO2 emissions, delivering a long-term reduction of 40 to 70% (c.f. 2015), whilst rapidly transitioning its LULUCF sector from being a source of emissions to one sequestering net CO_2 across.

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Appendix 1: Why the carbon budgets provided is different to the CCC's carbon budgets?

In 2008, the Committee on Climate Change (CCC) developed two sets of budgets, the 'intended' (which would be adopted following a global deal on emissions reduction) and the 'interim' (for the period before a global deal was reached). The budget proposals were designed in such a way that they could be met by purchasing EUAs (pollution permits within the EU Emissions Trading Scheme) and offset credits and/or by stretching the ambition in terms of decarbonisation (21,23). Both the 'intended' and 'interim' budgets are premised on the assumption that emissions of between 20-24 $GtCO_2$ by 2050 would represent an appropriate contribution by the UK towards global efforts (21). The CCC recommended that the UK's legislated five yearly carbon budgets, to third budget period (2022), are based on the interim budget and the intended budget thereafter (23).

There are a number of analytical reasons that our recommended emissions budgets and pathways are substantially smaller than those legislated by successive UK governments. Current UK budgets have an expected probability of exceeding 2°C of more than 56% (i.e. a *"likely"* chance of *exceeding* 2°C). According to the CCC the 'interim budget was premised on a 63% chance of exceeding 2°C and the 'intended' on an improved 56% chance of exceeding 2°C. However, these probabilities related to a global carbon budget range available prior to the publication of the IPCC's fifth assessment report, where the range of global carbon budgets for different temperatures was revised downwards. It is our understanding that the CCC's advice has not been substantially changed since its original conception and, consequently, the UK government's existing carbon budgets are for an even higher chance of exceeding 2°C than was originally reported (i.e. greater than a 56% and 63% chance of ***exceeding*** 2°C). By contrast, our analysis uses the IPCC's 'advice to authors' as a framework for transposing the wording of the Paris Agreement, *"...keep well below 2°C"* into a *"likely"* chance (66% to 100%) of ***not exceeding*** 2°C". This offers a much better probability of the UK delivering on its fair contribution to the Paris 2°C commitment (i.e. a smaller carbon budget) than that posited by the CCC and adopted by government (i.e. a larger carbon budget). The CCC budgets are based on global cumulative emissions of 1341 $GtCO_2$ post 2011[12] (21) compared to IPCC AR5 budget of 1010 $GtCO_2$ for a 66%-100% chance of not exceeding 2°C (6).

The CCC's scenarios assume a substantial uptake of speculative negative emission technologies (NETs), reducing the necessary levels of 'real' mitigation. Our analysis makes no allowance for NETs substituting for 'real' 2°C mitigation. It does however; suggest research and development of NETs to provide a theoretical possibility of delivering on Paris Article 2's *"...pursue efforts to limit the temperature increase to 1.5°C."*. Our analysis takes explicit account of the clear equity steer within the Paris Agreement, with its apportionment of the global 2°C budget to the UK premised on the early stabilisation and subsequent reduction in inequality in 'cumulative emissions' between citizens in wealthier and poorer nations. The CCC's budget allocation to the UK sees already high levels of inequality in individual cumulative emissions rise significantly for the coming three decades (until 2050). Put simply, our analysis apportions a much greater share of the 2°C carbon budget to the poorer nations than does the CCC; this is a major factor in explaining the difference between the CCC and our analysis. Our analysis notes how high levels of cement use, for which there are no major substitutes at scale, are essential for the development of poorer nations. Consequently, process emissions from cement are taken as a 'global overhead', rather than held solely as the responsibility of those poor nations striving to develop. This approach removes around 100$GtCO_2$ from the global 2°C carbon budget. The CCC approach holds poorer developing nations solely responsible for their process cement emissions, reducing significantly the fossil fuels they are able to use in progressing their development. A similar equity-based approach is taken with regards to deforestation, although the associated assumption in this analysis is that from 2018-2100 global forest restoration, reforestation and afforestation will broadly match the emissions from deforestation.

[12] Based on the CCC trajectory with global emissions peaking in 2016 and subsequent reductions at 4% per annum.