Carbon Savings from Peat Restoration

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1. Key Points

- For 2012, we estimate that abatement from existing projects amounts to 0.033 Mt CO_2e yr^{-1}, with a range of 0.021 – 0.044 Mt CO_2e yr^{-1}.
- As existing projects mature, and even with no new projects, projected annual abatement continues to increase. By 2027 it will amount to 0.050 Mt CO_2e yr^{-1}, with a range of 0.034 – 0.067 Mt CO_2e yr^{-1}.
- The current emissions from all Scottish peatlands are likely to be in the range of -3.9 (net uptake) to 5.1 Mt CO_2e yr^{-1}. In principle, carbon abatement in the range of 0.5 – 4.8 Mt CO_2e yr^{-1} could be possible by 2027, *if all potential areas identified are indeed restorable* to a net sequestering peatland within a reasonable time frame and *if restoration were to commence immediately in all areas.* A realistic estimate will fall somewhere below this.
- Data gaps and uncertainties remain significant.

2. Introduction

In our previous enquiry response (Artz et al., 2012c) we outlined the range of net potential abatement benefits from peatland restoration on a per hectare basis and gave an estimate of the likely area of peatland that could be available for some degree of improvement. We indicated that full abatement benefits would not be realised immediately but would involve a timeframe measured in several years to decades. Additionally, we stressed the paucity of relevant data on which each of these parameters (abatement per hectare, area and timeframe) were based and that there was considerable uncertainty associated with the cited values. There is no further evidence available at present whereby these ranges might be narrowed. The literature and data on which our conclusions were based are described in Artz et al. (2012c) and will not be repeated here.

The present enquiry may be divided into two tasks: the carbon savings from all peatland restoration carried out to date from the baseline year of 1990 and the potential for savings extending into the future to 2027. To our knowledge, the first task has never before been undertaken. There have been several estimates of the future potential. Bain (2010) estimated that 600 kha could be restored in Scotland by 2015 to give an annual saving of 2.7 Mt CO_2e (carbon dioxide equivalents). Subsequently, Bain et al. (2011) estimated a figure for the UK of >1

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million ha that could be restored by 2020 out of total of 1.8 million ha damaged, which would give an annual saving of 2.5 Mt CO_2e. Moxey (2011) suggested that 845 kha of grip blocking in the UK could save 2.2 Mt CO_2e yr^{-1}. However, these latter two references did not give a breakdown of the figures for Scotland.

3. Methods

There are significant data gaps and uncertainties in relation to both the extent of current and potential peatland restoration and the associated emissions savings. We have therefore had to make a number of assumptions in modelling emissions savings. This is very important to understand when interpreting the estimates set out in this paper.

Briefly, using the best available figures for the carbon balance of peatlands in a range of conditions and their respective areas, we have calculated the total net change in carbon (as CO_2e) following different restoration interventions. Additionally we have imposed a timeline that assumes that changes will take some time to take full effect. We have done this for both existing restoration projects and for all those areas that could be subject to future restoration efforts. A full explanation of our methods and assumptions is presented in Annex I.

4. Results

Carbon savings in Scotland from existing projects

In total we recorded 47 restoration projects that had been initiated since 1990. In some cases these were not individual peatlands but sub-areas that had been restored at different times. The majority were started about a decade ago (Figure 1), when many EU-Life projects began, but there appeared to be a more recent decrease in take-up rate. This might be due in part to failure to capture the most recent projects but a change in funding availability is a likely explanation. The total area restored came to 30.9 kha but the distribution of project areas was heavily skewed to the left with 50% of the projects having an area of <160 ha. The larger areas tended to be those with lesser intensive interventions such as grazing management, the exceptions being the wide areas of grip blocking in the Flow Country and at Flanders Moss.

Total annual abatement from the restoration was very slow over the first decade from 1990 but then accelerated with the increased efforts from 2001 onwards (Figure 2). We estimate that current abatement (for 2012) amounts to 0.033 Mt CO_2e yr^{-1}, with a 95% confidence interval of 0.021 – 0.044 Mt CO_2e yr^{-1} (Table 3). From 2012 to 2027 the projected annual abatement continues to increase, even with no new projects, as existing projects continue to mature. We estimate that abatement by 2027 will amount to 0.050 Mt CO_2e yr^{-1}, with a 95% confidence interval of 0.034 – 0.067 Mt CO_2e yr^{-1} (Table 3).

Figure 3 and Table 4 show the cumulative carbon savings from 1990 through to 2027. We estimate that current total savings amounts to 0.21 Mt CO_2e, with a 95% confidence interval of 0.13 – 0.29 Mt CO_2e, while total savings to 2027 will amount to 0.89 Mt CO_2e, with a 95% confidence interval of 0.60 – 1.18 Mt CO_2e.

Carbon savings in Scotland from future projects

Using our very simple and transparent assumptions of what a certain current land use on peat soil may represent in terms of current emissions, we would estimate the total current emissions from Scottish peatlands to range between a carbon sink of 3.86 Mt CO_2e yr^{-1} to a net source of 5.12 Mt CO_2e yr^{-1}. The upper estimate is higher than the estimated Scottish emissions from land use related to agriculture (2.8 Mt CO_2e) in 2009. The maximum value falls into the range of UK emissions as reported by Birkin et al. (2011) at 3.72 Mt (formerly 5.7). However, the most likely figure would be in the range of 1 – 2 Mt CO_2e yr^{-1} as there are a number of caveats in our calculations. For example, not all eroded areas have sufficient erosion features to affect the majority of the soil in that area. However, most eroded peatlands occur in large contiguous areas and hence it would be prudent to assume that much of the landscape is affected. More critical assessment of drainage would be required to verify whether the estimates of areas currently under wet and dry moorland vegetation are a good proxy of the effects of mild drainage. Older reports of the changes in land cover (Mackey and Shewry, 2001) suggested a loss of at least 70,000 ha of blanket bog that had vegetation converted towards heather moorland during the period 1947 to 1988, and similar conversions towards grassland. Although there may be little scope to reduce emissions from true heather moorlands, restoration management to encourage reversion of dry moorland areas that would have been wet heather moorland or blanket bog in the 1940s would bring net carbon benefits. However, in the absence of data on where drainage of peatlands has occurred, better estimates cannot be provided.

Use of the Excel calculator (see Annex I) suggests that carbon abatement in the range of 0.5 – 4.8 (mean 2.7) Mt CO_2e yr^{-1} with a cumulative saving in the range of 5.3 – 49.0 (mean 27.1) Mt CO_2e may be possible by 2027 (Tables 3 and 4, Figures 4 and 5), **if all potential areas identified are indeed restorable to a net sequestering peatland within a reasonable time frame and if restoration were to commence in all areas now**. This is, of course, unrealistic as there is an upper limit to what may be physically restored each year, but the data give an indication of which areas would provide the greatest benefits if restored. There is already evidence that peatlands may be adversely affected by negative water balances due to changes in rainfall patterns as a result of global climatic change and some areas may not be restorable to a peatland that sequesters carbon at the ranges currently identified. It may take more than 21 years in some scenarios to reach an end point that resembles a functioning peatland. For example, restoration of severely eroded gullies to functional blanket bog could easily take 50 years or more as both vegetation and hydrology need to re-establish. If all peatland restoration took 50 or 100 years to complete a succession to a functioning peatland, the above net carbon benefits would take even longer to reach. Our estimate is likely to take into account that not all areas identified in Table 2 are capable of being brought into a peatland state by any means of active restoration. The land use types that would achieve the highest emissions abatement through active restoration measures were always eroded bogs, afforested bogs and areas converted to improved grazing or moorland in our analyses, irrespective of the time limit to completed restoration used. It should be noted that the full abatement potential will not have been reached by 2027 (Figure 4).

5. Discussion

Our estimates indicate that currently the annual carbon savings from peatland restoration would only offset 0.24% of the 2009 Scottish transport emissions (13.6 Mt CO_2e) and by 2027, without any additional projects, would offset 0.37% (range 0.25 – 0.49%). This assumes that current projects are maintained where necessary, e.g. grazing levels managed, scrub removal reviewed, dams repaired, etc. However, additional restoration work is likely to offset a total of 4 – 35% of the 2009 Scottish transport emissions by 2027, if such work commences as soon as possible. The most critical areas that would benefit from targeting would be erosion control and restoration of sites currently converted to improved grazing, followed by removal of forestry on deep peat. However, the removal of forestry is only likely to be beneficial at the time when timber harvest becomes a concern in such areas. An estimate of the age of different commercial forestry stands across the Scottish peatlands and their current productivity would be required to adequately assess whether it would be beneficial or counter-productive to restore specific areas. An assessment of the merits of trying to convert heather moorland into peatland categories may require site-specific assessments. Restoration of peat cuttings (industrial or domestic) and areas currently used as arable land do not involve large areas and hence the contribution to the total is relatively low. However, there may be locally important carbon benefits and also benefits in terms of other ecosystem services from restoring such categories.

It is also important to bear in mind a number of caveats to these estimates. First, they are constrained by the previous estimates of potential abatement (Artz et al., 2012c) and we have already indicated that these are based on very few measured values, most of which were not from Scotland or even from the UK. Secondly, they assume that the restoration is largely successful. The report by Defra (2008) gave mean success rate of only 67%. However this was often a short-term assessment and the basis of what was "success" was unclear. Nevertheless it should be recognised that interventions may fail or may require further remedial action to maintain peatland integrity. Thirdly, we can safely assume that we have not captured all the existing projects. While we are confident in having listed the main areas, there will be many smaller projects that are unknown to us and our immediate contacts. Increasing the list would require further time and effort. To some extent these two latter effects may cancel each other out.

Additionally as we have mentioned, the potential for short-term methane emissions depressing the abatement potential and for more intermediate-term "lag-phase benefits" enhancing the abatement potential have not been included. These could be modelled but currently we do not have adequate data to support these effects. Again, we could assume that these to some extent cancel each other out and that the long-term abatement potential is unaffected.

Table 1. Carbon sequestration on 15 point scale and the peatland states to which they might apply

<table>
<tr><th rowspan="2">Index of condition</th><th rowspan="2">C balance (t CO_2e ha^{-1} yr^{-1})</th><th colspan="9">Range of emissions factors for land use class</th></tr>
<tr><th>near-natural</th><th>bare peat[1]</th><th>Eroded[1]</th><th>afforested</th><th>wet or dry heath[1] (drainage)</th><th>domestic cuttings[1] (drainage)</th><th>grazing conversion[1] (drainage)</th><th>improved grassland[1]</th><th>arable conversion[1]</th></tr>
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Note: Emission factor ranges for different land use categories are based on Artz et al (2012c), with estimated splits into severity ranges for figures indicated with [1].

Table 2. Likely emissions ranges from current land use on peat.

Land use category	Severity	Occurrence of land use on soil types (ha)				Current Emissions ($Mt\ CO_2e\ yr^{-1}$)
		Basin peat	Blanket bog	Semi-confined peat	Total area	
Near-natural		19,957	296,814	54,583	371,354	-1.37 – 0.11
Bare		1,827	1,642	99	3,567	0 – 0.01
Eroded(*)		3,911	235,094	29,369	268,375	0 – 1.48
Afforested		21,041	196,582	120,052	337,676	-3.04 – 1.62
Dry vegetation types (Drained*)	Mild (Wet or dry heath cover)	6,027	264,574	302,402	573,003	-0.03 – 0.57
	Moderate (domestic peat cutting)	2,537	29,149	3,359	35,044	0.01 – 0.07
	Major (smooth or rough grass cover conversion)	6,133	77,707	40,438	124,278	0.12 – 0.68
Cultivated	Improved grass land conversion	10,017	17,854	16,006	43,877	0.40 – 0.53
	Arable land conversion	3,369	183	23	3,575	0.04 – 0.05
Total		**74,818**	**1,119,599**	**566,332**	**1,760,749**	**-3.86 – 5.12**

Note: Some areas cannot be allocated with sufficient certainty from the land cover categories within the LCS88; these are indicated with *.

Table 3. Annual carbon savings (Mt CO_2e yr^{-1}), mean and range (95% confidence interval).

Projects	2012	2017	2022	2027
Existing	0.033 0.021 – 0.044	0.043 0.028 – 0.057	0.048 0.032 – 0.064	0.050 0.034 – 0.067
Total potential (assuming all possible areas restored within 2012 to restoration end point within a realistic timeframe)	0	1.5 0.3 – 2.6	2.2 0.4 – 4.0	2.7 0.5 – 4.8

Table 4. Cumulative carbon savings (Mt CO_2e), mean and range (95% confidence interval).

Projects	2012	2017	2022	2027
Existing	0.21 0.13 – 0.29	0.41 0.27 – 0.55	0.64 0.43 – 0.85	0.89 0.60 – 1.18
Total potential (assuming all possible areas restored within 2012 to restoration end point within a realistic timeframe)	0	4.8 0.8 – 8.7	14.5 2.7 – 26.3	27.1 5.3 – 49.0

Figure 1. Timeline of peatland restoration project initiation

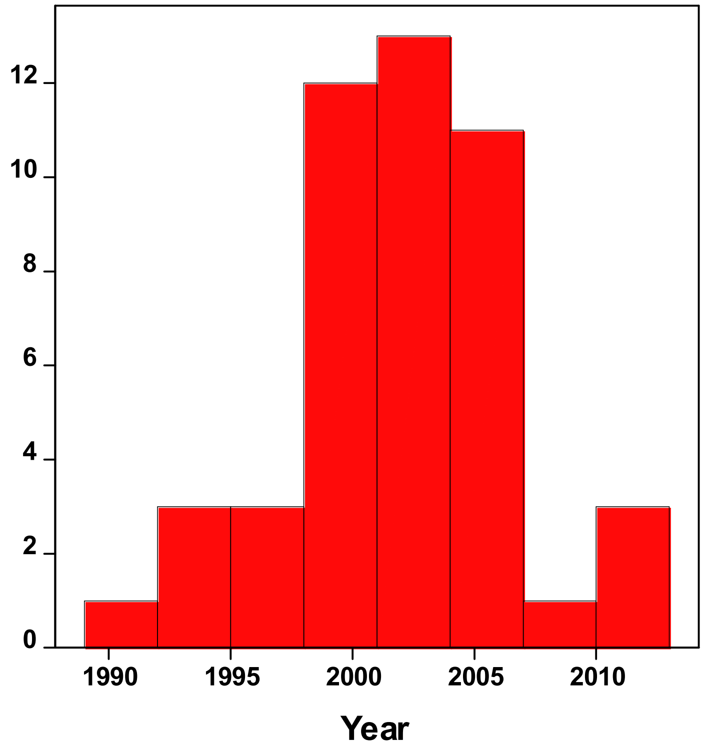


Figure 2. Annual abatement from all current peatland restoration (1990–2012) projected to 2027. Bars indicate standard deviation.

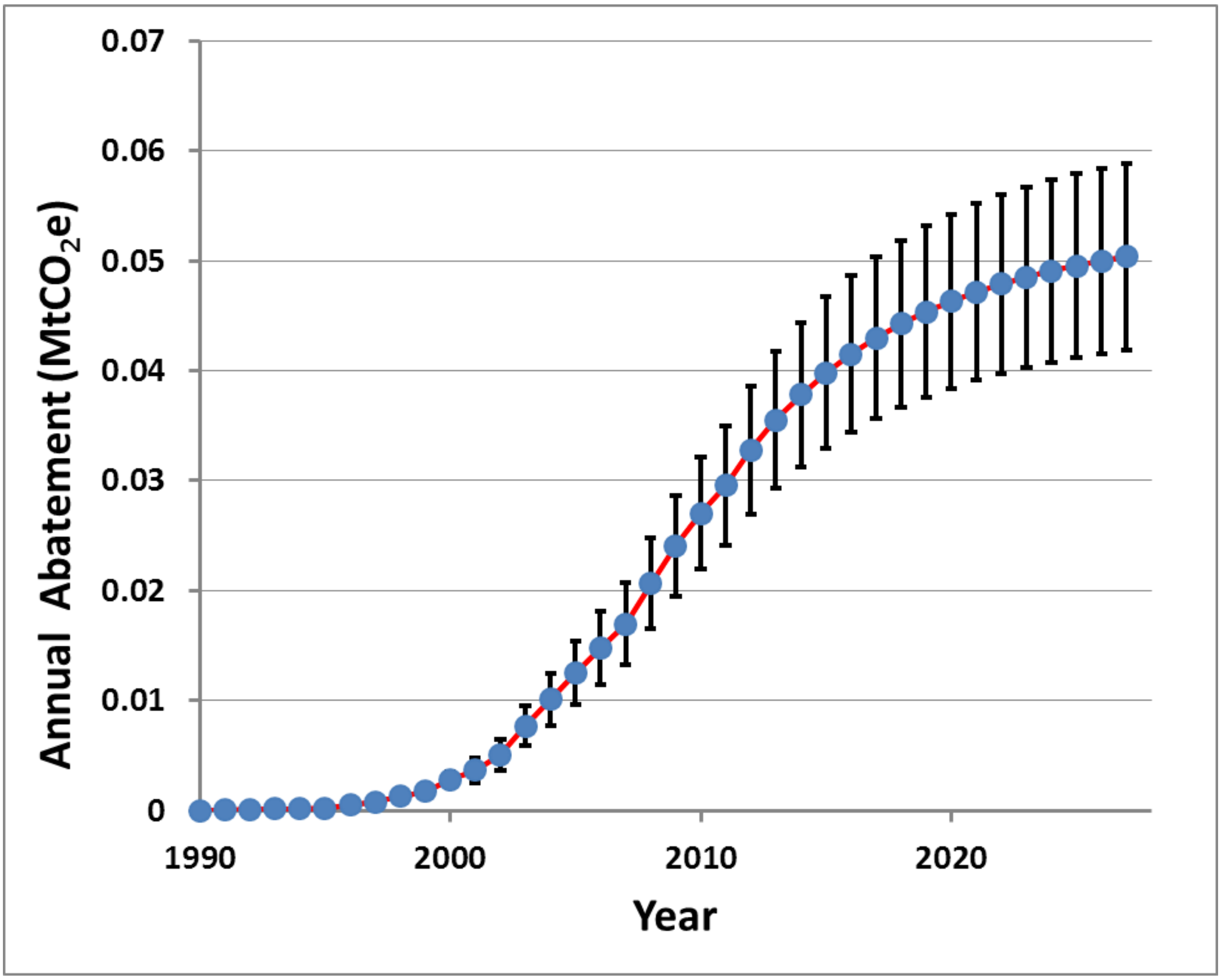


Figure 3. Cumulative abatement from all current peatland restoration (1990–2012) projected to 2027. Bars indicate standard deviation.

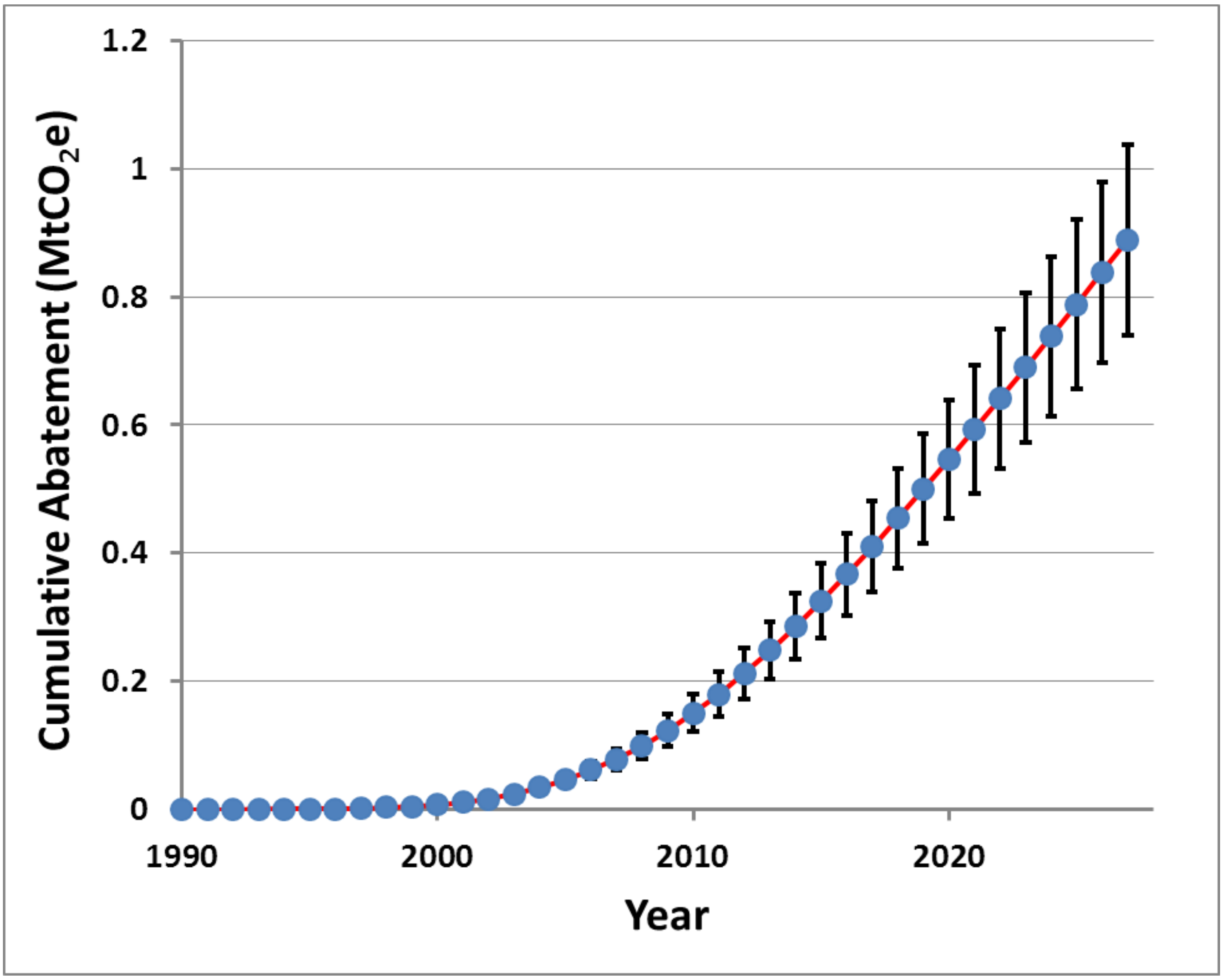


Figure 4. Annual abatement from all potential peatland restoration – all started in 2012 and projected to 2027. Bars indicate standard deviation. Time to restoration was set by condition class (see text for details).

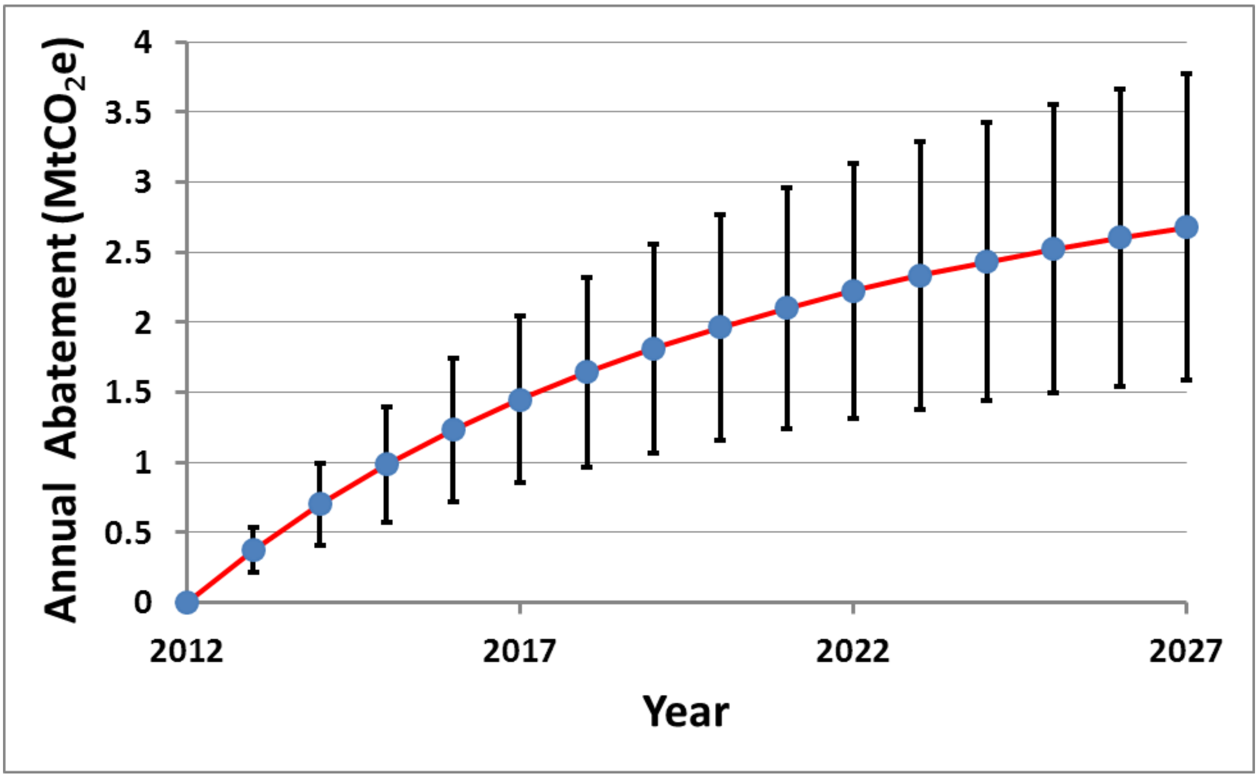
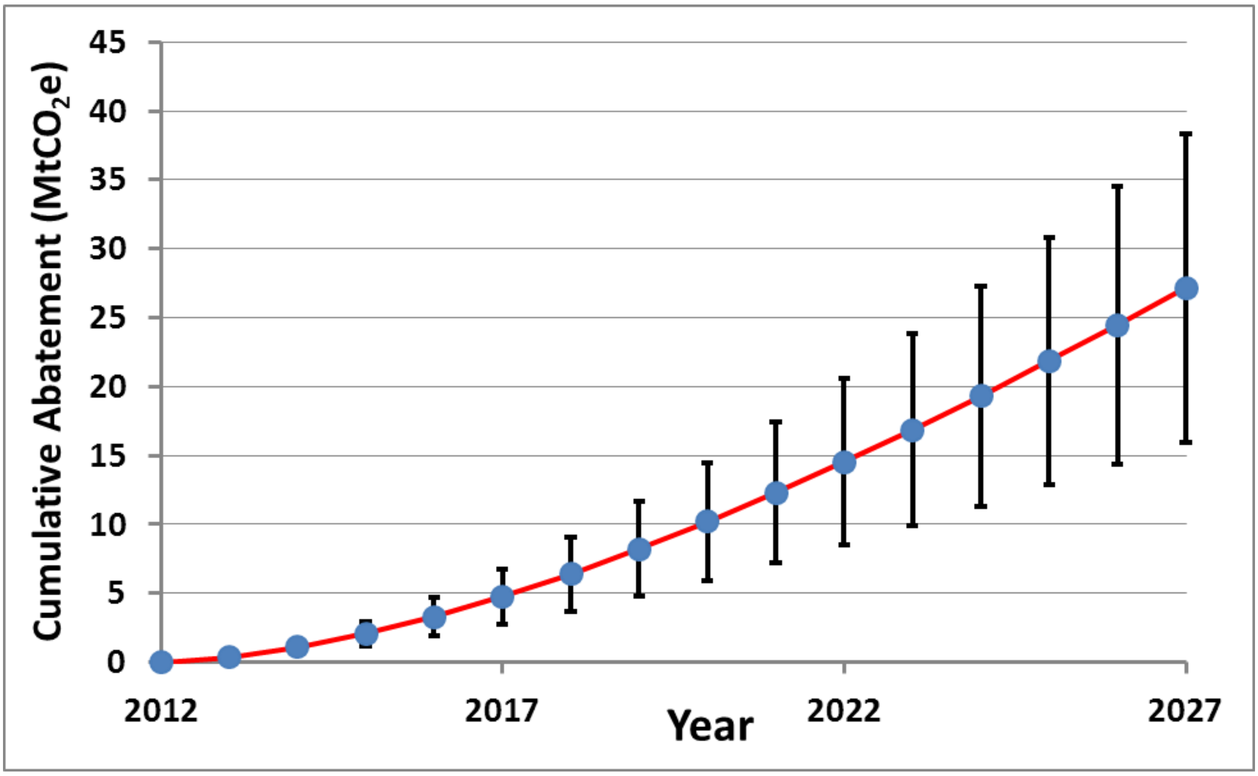


Figure 5. Cumulative abatement from all potential peatland restoration – all started in 2012 and projected to 2027. Bars indicate standard deviation. Time to restoration was set by condition class (see text for details).



Further information

Please contact Steve Chapman or Rebekka Artz at the James Hutton Institute

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Annex I – Methodology

Estimating carbon savings in Scotland from existing projects

This task required a collation of all the restoration projects undertaken in Scotland since 1990. It is recognised that during the 1990s most of these were not instigated with carbon savings in mind, and the majority were carried out in order to restore the habitat, enhance biodiversity and to improve general peatland 'condition'. The motivation to provide carbon savings has only more recently been recognised as a valuable co-benefit of restoration. Unfortunately there is no centralised audit of restoration projects. The Peatland Compendium (Defra, 2008) attempted to capture this information for the UK but the initial report only showed three sites for Scotland. However, a follow-up website has extended this to 12 projects (http://peatlands.org.uk/?q=map/node; accessed 11/06/12). Some of these, such as the Grampian Lowland Bog Scheme, actually cover several sites, though details are not given on the website. Recently commissioned studies (Artz et al., 2012a; Artz et al., 2012b) and personal contacts with RSPB, SNH, SWT and the Forestry Commission have given us details on further projects. It was important to gather information on the area of restoration, the date of restoration and the management interventions. The latter can then give some indication of the peatland condition prior to, and subsequent to, the restoration process, recognising that restoration was often implemented in stages.

The next step was to assign a value for the carbon sequestration before and after restoration, i.e. at the final endpoint, dependent upon the peatland condition and the particular intervention. Since there is no site where these details are known we have used expert judgement to apply a 15-point scale, varying between +15 and -9 t CO_2e ha^{-1} yr^{-1} (based upon Table 1 in Artz et al., 2012c), where a positive value indicates net carbon loss and a negative value indicates carbon sequestration (Table 1). However, for the afforested areas these were set at -4 t CO_2e ha^{-1} yr^{-1} in place of -9 t CO_2e ha^{-1} yr^{-1} as this corresponded to the expected maximum yield for very wet, nutrient limited conditions (M. Perks, pers. comm.), as found at the Flow Country sites where most of the restoration of afforested sites has occurred. A change in value from point 4 to point 14 (eroded or drained to near-natural) would result in a net abatement potential of 9.2 t CO_2e ha^{-1} yr^{-1}, the maximum estimated by Artz et al. (2012c). Points 1 to 3 only apply to peat currently under more intensive agricultural use, not found in existing projects. The initial condition was judged on whether the site was near-natural (only slightly impacted), drained, afforested or bare peat. The final condition was judged on the extent of the management intervention going from reductions in grazing and muirburn, scrub clearance, grip blocking, dam installation and other hydrological controls, surface stabilization and reseeding, through to deforestation.

Next we assumed that any change in carbon sequestration would follow an exponential trajectory such that 95% of the final value would be achieved within a range of 10–80 years (area-weighted mean of 21.0 years). There are no specific data for the progress of peatland restoration to support such a form. However, simple exponential curves between two equilibria have commonly been applied to changes in soil carbon in general (Cannell et al., 1999), and are used in the UK National Inventory of greenhouse gas emissions from Land Use, Land-Use Change and Forestry. Site-specific ranges were set using expert judgement, depending upon how readily the site could be restored. We have ignored possible complications through temporary enhancement of methane emissions following grip blocking (giving a more positive value for the CO_2e) or possible "lag-phase benefits" where some intermediate stage might have a greater carbon sequestration value than the final stage. The starting point was taken as the year of intervention or the first year of intervention where this was spread over several years.

The annual carbon benefit per site was calculated as the difference between the carbon exchange in that year and that calculated for 1990. These values were projected to 2027. The sum of all sites was then calculated to give a total abatement value for Scotland, also projected to 2027. This simple model was implemented within an Excel spreadsheet. Uncertainty was estimated by allowing the site condition value to vary over the selected range for both initial and final condition. Values were selected at random from a normal distribution with mean as mean of the range and standard deviation as the range/3.92; this effectively assumes that the range is a 95% confidence interval. The net abatement is the difference between initial and final conditions. This would mean that at some sites there would be virtually no change in carbon sequestration or even transition to a worse state in a few cases. Additionally, for each site the time period for reaching 95% of the final value was varied randomly over the set range. The model was run 999 times in order to generate the range of uncertainty. We did not apply any uncertainty estimate to the areas of restoration involved as in most cases these are reasonably well characterised. In a few cases only the total area of the site was known whereas it was also known that the restoration only applied to a small fraction of the total; at these sites the restored area was estimated to be 2-10% of the total, depending upon the description of the management.

Estimating carbon savings in Scotland from future projects

We estimated the total area of peatlands in Scotland that are under peatland or other bog vegetation cover by truncating the Land Cover of Scotland GIS map (1988) to only the 1.7 mi ha of peat soils, as defined by the 1:250,000 Soils of Scotland. Within this area, we queried the extent of vegetation classes that may be indicative of the condition classes used in Artz et al. (2010c) to estimate emissions factors. We assumed any peat area that had peatland vegetation cover without erosion or peat cutting features to be in a semi-natural condition. As there is no good inventory of the true extent of bare peat through peat cutting and erosion, or data on the location, severity and effect of drainage, we made some assumptions based on land cover in 1988. Industrially harvested peatlands were assumed to be bare (Table 2), as there have been few initiatives to actively re-seed vegetation since 1990 on former peat production areas. In the case of eroded peatland, the stated figures apply to the total land area that shows dominant erosion features within a polygon (Table 2). These figures may therefore be an overestimate of the total area involved.

As there is no national database of drainage features, we made an assumption that drained peatlands would show some vegetation conversion to wet or dry moorland or grassland cover, depending on the severity of the drainage. Although this may also be an overestimate as some peaty areas are naturally moorland rather than peatland, various earlier reports have stated a substantial increase in moorland area at the expense of blanket bog since 1940 (Mackey and Shewry, 2001) and hence we used this as a cautious proxy. Also included in this category were remnant domestic peat cutting areas as these were assumed to have been drained prior to peat cutting. As the original emissions factor range for the bare peat and drained peat categories were quite wide, we assumed that mild drainage resulted in vegetation conversion to heather moor types of land cover, that domestic peat cutting would be in the mid-range of emissions for drained areas and that the most severe types of drainage would be associated with conversion to rough grassland cover.

Forestry cover was estimated through data from both the LCS88 and Forestry Commission data as it was deemed that the 1988 data alone would be too inaccurate as several large scale plantations were in rotation or still in preparation at that point. Overlays of current Forestry Commission data with all potential forestry classes in the LCS88 such as forestry gripping and young plantation categories produced a match of >85% in area, but the more current Forestry Commission data showed an increase in forestry around many of the 1988 plantations . We also split the cultivated land use category into peatlands converted to improved grazing (use of lime and fertilisers and covered with high grazing value mixtures of grass and clover) and conversions to fully arable land (land under a rotation of arable crops and short-ley grassland). From these areas, we calculated the range of current emissions using the emission factors in Table 2 and the likely net range of current emissions from Scottish peatlands.

Secondly, we estimated the carbon abatement potential for restoration of the entire area of each of these land use conversion classes using the same model described above for existing projects. As it is likely that areas which would require predominantly a change in land management such as changes in grazing regime or mild scrub removal would show a recovery to a semi-natural state more rapidly, and conversely restoration of bare peat to a blanket bog would take much longer, we again tried to encompass variability in the time it takes to complete such restoration efforts. Model runs were set as follows for time to 95% of completed restoration: bare (30-60 years), eroded (30-80), afforested (20-50 years), moorland cover (10-25 years), domestic peat cuttings (15-30 years), rough grassland (20-50 years), improved grazing (25-60 years) and arable land (30-80 years).

Table 5. Yearly breakdown of total potential annual carbon savings (Mt $CO_2e\ yr^{-1}$); mean, standard deviation and 95% confidence interval (Min–Max).

Year	Mean	SD	Min	Max
2012	0.00	0.00	0.00	0.00
2013	0.38	0.16	0.06	0.70
2014	0.70	0.30	0.11	1.29
2015	0.99	0.42	0.17	1.81
2016	1.23	0.52	0.22	2.25
2017	1.45	0.61	0.26	2.64
2018	1.65	0.68	0.30	2.99
2019	1.82	0.75	0.34	3.29
2020	1.97	0.81	0.38	3.57
2021	2.11	0.87	0.41	3.81
2022	2.23	0.92	0.43	4.03
2023	2.34	0.96	0.46	4.22
2024	2.44	1.00	0.48	4.40
2025	2.53	1.04	0.50	4.56
2026	2.61	1.07	0.52	4.71
2027	2.69	1.10	0.54	4.84