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AFOLU accounting: implication for implementing peatland restoration – costs and benefits

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1. Key Points

- Current restoration effort, if coordinated, could amount to 6500 ha yr^{-1} and cost about £ 5.7 M yr^{-1}.
- This could give an annual abatement by 2027 in the range 0.13 – 0.26 Mt CO_2e yr^{-1}, which would continue to increase as peatlands mature.
- A three-fold increase in effort would seem feasible and could give an annual abatement in the range of 0.33 – 0.70 Mt CO_2e yr^{-1} by 2027.
- A ten-fold increase in effort would see the restoration of 45% of Scotland's degraded peatlands by 2027 and could give an annual abatement in the range of 0.67 – 1.75 Mt CO_2e yr^{-1} by then, but achieving this level of input is probably unrealistic.
- Although data is extremely limited, what there is indicates that increased methane emissions from restoring peatlands by drain blocking may offset the overall reduction in global warming potential by around 10-20%, although considerable further work is required to reduce the huge uncertainty in this estimate for Scottish conditions. Other approaches to restoration where there is a reduction in grazing pressure are likely to result in lower methane emissions from livestock, thereby further adding to the overall reduction in climate forcing.

2. Introduction

The UNFCCC meeting in Cancun in December 2010 acknowledged a new activity called "rewetting and drainage" in which the reduction of GHG emissions from the rewetting of drained wetlands, including peatlands, could be accounted for in National Inventory Reports. Also, under the Verified Carbon Standard Program, carbon offsetting under the Peatland Rewetting and Conservation module of the AFOLU Guidelines are now possible (Wilson *et al.*, 2012). Hence, in addition to the very real benefits of peatland restoration on the ground, it is now possible for them to be recognised at the international level.

Artz *et al.* (2012) summarized provisional emission factors from the restoration of peatland under a range of land use types, emphasizing that these are based upon very few measured values. Based on these emission factors, Chapman *et al*. (2012) estimated the carbon savings from a compilation of restoration projects initiated since 1990. The carbon savings from all possible restoration of degraded peatlands in Scotland was then estimated. The assumption was that this was all completed in 2012 and so produced very much an upper limit or theoretical annual abatement figure, which could be used to judge the value of peatland restoration in comparison to other mitigation options.

There is no single figure for the financial costs of peatland restoration, since so much depends upon the level of intervention required and factors such as scale, remoteness and terrain. The Compendium of UK Peat Restoration and Management Projects (Holden *et al.*, 2008) gives the most comprehensive information on overall costs though without detailing the specific interventions used. They cite the median cost as £1600 ha^{-1}, though their data suggest quite a large spread of values. In several projects the cost of land purchase was included. They indicate that 55% of the costs were for “practical works”, i.e. excluding land purchase, monitoring or costs “not attributed”. This would give £880 ha^{-1}. Moxey (2011) cited these figures in his economic appraisal of peatland restoration though he actually used a value of £1500 ha^{-1}. He also gave a value for grip blocking for as little as £240 ha^{-1} and suggested that costs might be £450 ha^{-1} for limited monitoring and infrequent or minor management spread out over 20 years. A similar figure of £300 (€400) ha^{-1} has been quoted for the restoration of cutaway bog in Ireland (Wilson *et al.*, 2012).

The Crichton Carbon Centre (CCC) have considered costs for various types of restoration, as follows*:*

- Drain (grip) blocking: “for lightly drained blanket bogs, as little as £60 per hectare once the operator is up to speed (costs are very variable, according to weather and site conditions)”
- Deer Management by Fencing: £500 per ha (plus maintenance) for 100ha at £10 per metre, with allowance for difficult terrain; such restoration can bring other benefits, such as woodland regeneration and landscape improvement, which might be considered to reduce peatland restoration costs by a third, i.e. to about £350 per ha.

At the other end of the scale, tree removal by helicopter was cited as costing £3200 ha^{-1} (Brooks & Stoneman, 1997). It would be advantageous to have a range of costs that could be attributed to the types of interventions that might be applied in Scotland, ranging from simple grazing reductions to full-scale tree removal, hydrological works and reseeding.

The objective here was to estimate what the costs and benefits of a major peatland restoration would be, based upon information about actual restoration in Scotland to date and applying a more realistic rate of restoration which would be spread out over the coming years.

3. Methods

In order to estimate the annual restoration rates that have been achieved to date, we have re-examined the dataset collected previously on Scottish restoration projects (Chapman *et al.*, 2012), bearing in mind that this set may not have covered everything.

In order to project peatland restoration at various rates into the future we have used our simple Excel model of the progress of peatland restoration with all the ancillary caveats that should be borne in mind, as previously described (Chapman *et al.*, 2012).

4. Results

Rates of restoration (1990-2011)

In our previous assessment (Chapman *et al.*, 2012) the total area restored over 22 years was 30870 ha , giving a mean annual restoration rate of 1403 ha yr^{-1}.This figure includes some large areas (22520 ha) which were only subjected to grazing management, but at the same time probably underestimates the total area restored as not all projects have been included, particularly those with SRDP funding. Additionally, the restoration rate has been sporadic over the years, with the majority of projects starting in 2001-2007. Table 1 summarises the maximum areas restored in any particular year in each of the major land use classes.

During the assessment period, there were no specific cases of bare peat restoration or of any conversions from cultivated peat and the area of eroded peat restored was from only one small project. While these maximum areas of restoration in each land use category were achieved in different years, there is no intrinsic reason for not assuming that these rates could all have been achieved in one year if coordinated, since they were carried out by different groups in different parts of the country. We could also assume that an area of eroded peat similar to that of afforested peat (740 ha) could have been restored had effort been put into this category. The restoration of completely bare peat is technically more difficult, so we could assume that half the area (370 ha) could be tackled. In the absence of more detailed information, we could also assume that 740 ha of each of the cultivated classes could be restored. This would give a total of 6530 ha peatland of various categories restored.

For the purpose of estimating what might be a realistic annual target for peatland restoration, we can start with the above figures, termed the aggregated current restoration rate, and then consider what might be achieved with increased effort. If we assume that the current restoration is limited by funding, then it might be possible to consider further scenarios of a three-fold or ten-fold increase in support. At some point, there will be some other physical limitation, e.g. of skills, personnel or equipment, which might limit the amount of restoration that could be accomplished in any one year.

Projecting peatland restoration to 2027 under three scenarios

Implementing year-on-year peatland restoration at the aggregated current rate will result in an annual abatement of 0.19 Mt $CO_2e\ yr^{-1}$, with a range (95% confidence interval) of 0.13 – 0.26 Mt $CO_2e\ yr^{-1}$, by 2027 (Figure 1). Since the total areas of arable land conversion and of bare peat are relatively small (see Chapman *et al.*, 2012), these would be completed in 2016 and 2021, respectively. As seen in the figure, the annual abatement is small at first but continues to increase as more land is restored each year and as each previous parcel of land matures in its capacity for carbon sequestration. This capacity would continue to increase beyond 2027 even if all further restoration ceased then. By 2027, the total cumulative abatement would be 1.28 Mt CO_2e, range 0.84 – 1.71 Mt CO_2e (Figure 2).

Increasing the restoration effort three-fold will result in an annual abatement of 0.52 Mt $CO_2e\ yr^{-1}$, with a range of 0.33 – 0.70 Mt $CO_2e\ yr^{-1}$, by 2027 (Figure 3). The total areas of arable land conversion and of bare peat would be completed in 2013 and 2015, respectively, and the area of moderate category drainage by 2024. This explains why the annual abatement is less than three times that with only the aggregated current restoration rate. By 2027 the total cumulative abatement would be 3.35 Mt CO_2e, range 2.14 – 4.56 Mt CO_2e (Figure 4).

Increasing the restoration effort ten-fold will result in an annual abatement of 1.21 Mt $CO_2e\ yr^{-1}$, with a range of 0.67 – 1.75 Mt $CO_2e\ yr^{-1}$, by 2027 (Figure 5). The total areas of arable land conversion and of bare peat would be completed in 2012. The area of moderate category drainage would be completed by 2015, the area of improved grass by 2017 and the area of major category drainage by 2022. Again, this explains why the annual abatement is rather less than ten times that with only the aggregated current restoration rate. Of course, it is possible that once these areas were completed, effort could be deployed to other areas but this has not been implemented in the model as run. If it had been, then we would obtain a full three-fold and ten-fold increase in the annual abatement values. Clearly, at some point in the future, all restoration would be completed, resulting in the annual abatement predicted by Chapman *et al.* (2012) of over 3 Mt CO_2e yr^{-1}. Hence in this ten-fold scenario we would obtain about 40% of what might be theoretically possible. By 2027, the total cumulative abatement would be 8.76 Mt CO_2e, range 5.11 – 12.42 Mt CO_2e (Figure 6).

Costs of restoration

A provisional total annual cost of restoration may be calculated assuming an average cost of £880 ha^{-1}. Applying this to all areas restored each year in the "current optimised" model runs gives £ 5.7M for 2012, decreasing to £ 4.8M for 2027 as some areas of land use (peatland type) are completed before this year. With a three-fold increase in effort, the figures are £ 17M for 2012, decreasing to £ 12M for 2027. With a ten-fold increase in effort, the figures are £ 54M, decreasing to £ 22M for 2027. It should be emphasized that these are very indicative until further cost data can be collated, with an estimated uncertainty in the region of a factor of four in either direction.

A more detailed cost-benefit analysis will require further cost data.

Methane emissions arising from peatland restoration

Restoring peatlands by rewetting potentially releases methane (CH_4). Methane is also a greenhouse gas, but is 75 times more potent than CO_2 in terms of its global warming potential (GWP) over a 20-year period, although, due to its short-lived nature in the atmosphere compared to CO_2, this ratio drops to 25 times more potent over a 100-year period, the period normally used for global warming calculations. Methane is produced by archaea (formerly called archaebacteria) under conditions with zero oxygen (anaerobiosis), as can occur below the water table in peatlands. If the water table is raised to help restore the peat this can result in an increase in CH_4 emissions due to the increase in anaerobic conditions, the reduction in aerobic peat that would otherwise oxidize any generated methane, and from an increase in organic material from vegetation growth reaching anaerobic zones. Given that many peatlands are subject to gripping (drainage), this CH_4 production may occur in 'hotspots' in filled ditches rather than homogenously across the restored area (Cooper *et al.*, 2012) . These CH_4 emissions could offset any increase in carbon sequestration in global warming terms.

There is a paucity of data to estimate the relative magnitude of this increased CH_4 emission from restoration, but based on the review of Baird *et al.* (2009) and some recent work in Wales, we summarise in Table 2 results from the few studies available.

There is considerable variation in these CH_4 emission figures, ranging from 0.32 to 9.5 tCO_2e ha^{-1} yr^{-1}, although several of the values appear to congregate around 1-2 tCO_2e ha^{-1} yr^{-1}. However, there are several caveats. The figures of Worrall *et al*. (2009) were not actual measurements, but were estimated using an empirical equation based on water table depths, some of which were actual measurements, and some of which were estimated from a catchment water balance model. As such, they are subject to considerable uncertainty, which the authors estimate to be around 80%. Similarly, the figures of Waddington and Day (2007) show a high total GWP figure, which the authors ascribed to the use of straw to block drains, which also provided an input of readily decomposable carbon for methanogenic bacteria to consume. For the results from Cooper *et al*. (2012), the increase in CH_4 emissions was strongly influenced by the establishment of *Eriophorum* on the infilled ditches, which is very dependent on the method of restoration used and which the authors acknowledge might not have been the best one in this respect – establishment of *Sphagnum*, for example, would be expected to reduce CH_4 emissions. Moreover, measurements were taken only two years after restoration, so there is a strong likelihood that part of the observed increase was transient. Nevertheless, these figures, and those included in the meta-analysis of Worrall *et al*.(2011), all suggest that there is an increase in CH_4 flux resulting from re-wetting of peatland.

It is interesting to compare these CH_4 emission values with that from an undisturbed pristine bog – Macdonald *et al*. (1998) found CH_4 fluxes for a blanket bog in Scotland between 0.16–13.5 Mg C km^{-2} yr^{-1}, which converts to 0.05 – 4.5 tCO_2e ha^{-1} yr^{-1}. Hargreaves and Fowler (1998), using the same site data, estimated an annual emission of 1.7 tCO_2e ha^{-1}. A similar value of 1.5 tCO_2e ha^{-1} yr^{-1} was obtained from an Irish blanket bog (Laine *et al*., 2007). This would suggest that rewetted bogs reach a similar level of CH_4 emission to undisturbed ones, a least over the initial period of restoration. However, again it should be remembered that this is only indicative at best, as there is considerable uncertainty in these figures, not least because the restoration figures are from locations outside Scotland, and come from different types of bogs, with different types of vegetation.

In terms of the proportion of CH_4 emissions within total GWP, it seems from several of the studies above that it is in the order of 10-15%, although this could be as high as 28%. However again, there is considerable uncertainty in this. If we compare the ball-park figure mentioned above of around 1-2 tCO_2e ha^{-1} yr^{-1} CH_4 emissions to the net potential abatement benefits from peatland restoration calculated in an earlier CXC call-down ranging from 0.6 to - 8.3 t CO_2e ha^{-1} yr^{-1} (based on CO_2 emissions saved from losses from degrading peat as well as C sequestration from vegetation growth, but not including CH_4 emissions), then CH_4 emissions could either completely offset any CO_2-saving benefits from restoration at the lower end of the range or reduce it by about 18% at the upper end of the range. Clearly there is a huge range in these figures, for which further research is necessary to try and reduce.

Other sources of variation and hence uncertainty in methane emission estimates include:

1. Impact of vegetation – several vascular plants possess aerenchyma, air channels running the length of the plant to provide oxygen for the roots to survive in anaerobic environment, but which also influence CH_4 dynamics, as oxygen inhibits CH_4-producing bacteria, but which also provide a conduit for CH_4 to escape directly to the atmosphere without being consumed by methanotrophic bacteria. *Sphagnum* moss does not facilitate CH_4 release in this way. In sites containing a range of vegetation types, there may be high spatial variability in CH_4 emissions.
2. Inter-annual variability – variations in temperature and rainfall, in particular, can cause huge impacts on CH_4 dynamics, potentially turning a peatland from a net sink for CO_2 one year into a net source the next year. This can make it difficult to compare pristine, degraded and restored peatlands at different sites and years (as we have done above) unless paired comparisons under the same weather conditions are made. There is also the question of whether CH_4 emissions follow a temporal pattern of sudden increase following rewetting due to the increased new organic material introduced, then a decline as this is decomposed leaving relatively inactive organic material (i.e. a transient pulse), or whether it continues for some time. Certainly, in the study of Tuittila *et al*.(2000), CH_4 emissions increased gradually compared to the control site during the three years following rewetting. How long this might continue in this way needs to be determined.
3. Sulphate/nitrate deposition – both sulphate and nitrate ions are alternate electron acceptors that specific bacteria can use to decompose substrate, thereby competing with CH_4-producing bacteria and hence reducing CH_4 emissions to the atmosphere. Over the last twenty years or so, sulphate deposition has decreased over the UK due to clean-air policies, which could result in higher CH_4 emissions. Comparison of fluxes measured at different times, therefore, may not be directly comparable.

5. Discussion

Looking at past performance, an annual restoration rate in Scotland of around 6500 ha would seem perfectly possible. While this represents a compilation of effort in different areas and in different years, the staff and equipment utilised were different, such that a focussed effort could have produced that result in one year.

Additionally, these data were from all known restoration projects and there may well have been others not included. However, some of the areas included were from relatively ‘easy’ interventions such as removal of grazing and muirburn. A three-fold increase in effort would put this up to an annual value around 20000 ha. It is likely that this would begin to stretch resources in terms of man-power with the necessary skills. It has been suggested that 10000 ha might be an upper limit for grip blocking (Mary-Ann Smyth, pers. comm.), though this is only one of many interventions. Possibly, there would be an initial period where planning, knowledge exchange and intensive training would be required which might limit the rate in the early years of a more intensive program. By comparison, afforestation rates are targeted to be 9000 ha yr^{-1} (Scottish Executive, 2006) though tree planting is a much more intensive and costly process and forest cycle harvesting and subsequent wood use makes this a limited abatement option in the long run. A ten-fold increase in effort would put even more strain on resources and it would be unlikely that a programme of this intensity could be implemented straight away. Achieving this rate, assuming no financial constraints, would require several years’ start-up time and is probably unrealistic.

The above calculations on total costs – based on an estimated cost per hectare of £880 are summarised in Table 3. Use of the Crichton Carbon Centre estimates of “as little as £60 per ha” for grip blocking, or £350 per ha for deer fencing, or say £200 per ha on average, would reduce these totals considerably, e.g. to a mid-period (year 2020) annual figure of about £4M.

For comparison, approved Scottish Government funding on SRDP Rural Priorities Options to March 2012 (i.e. over about 4 years, but likely to represent the bulk of public expenditure over the 6/7-year period of the SRDP) totalled about £500M, or say £100M per year. This compares with about £433M per year on Single Farm Payments, and £65M per year on Less Favoured Area Support Scheme payments (Scottish Government, 2010) over the same period. Thus the amounts involved are relatively small, and decreasing out to 2027.

Of the £500M Rural Priorities total just cited, the Options given in Table 4 appear to be most comparable with peatland restoration work. Figures on the areas involved in these Options appear to be unavailable, but from the costs per case calculated above, it can be seen that the average approval on these Options is around £15,000. At £200 per ha, an approval of similar financial size would pay for about 75 ha of peatland restoration on average.

The above costs are for Scottish Government (SG) payments, of which about a third come from EU sources to which the UK government contributes and two thirds from SG’s own resources mostly funded by a UK block grant. The calculations are complex but would reduce the net SG cost somewhat. As against this, there are considerable transaction costs incurred by both private and public parties to any peatland restoration payment award; Falconer and Whitby (1999) estimated that public administrative costs in UK agri-environment schemes averaged 48% of the compensation paid and Falconer (2000) estimated the private transaction costs to farmers as around 5% of the compensation although the range is likely to be substantial (both cited in CRER/CJC, 2002). A week of professional time spent by private agents (farmers or their advisors) and/or officials at £500 per day in preparing a restoration application (including travel expenses, etc.) means a transaction cost of £2500 per case (whether approved or not). However, greater familiarity with a scheme – by individual farmers as individuals or as a group, or by official administrative staff – is likely to lower these costs considerably. This suggests targeting a new scheme to particular regions, or perhaps encouraging extensions of restoration schemes within particular estates.

A review of the limited data available suggests that restoring peatlands by drain blocking and raising the water-table is likely to result in an increase in methane emissions due to both an increase in fresh organic material from enhanced vegetation growth and from an increase in the anaerobic conditions conducive to methane production. The impact of this increase on the reduction in total Global Warming Potential of restoring peatlands may be in the order of 10-20%. However, there is considerable variation in these estimates due to spatial (vegetation type) and temporal (interannual weather) variability. Other approaches to peatland restoration, such as reducing grazing pressure from livestock, is likely to not only reduce methane emissions from the livestock but also reduce fluvial losses of carbon as well as enhance carbon sequestration. Clearly further research is needed on comparing whole-system carbon/GHG balances rather than on the soil component alone.

6. Acknowledgements

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7. Tables and figures

Table 1. Maximum areas restored in any particular year in each of the major land use classes and areas used for the aggregated current restoration rate in the restoration model.

Land use category	Severity	Area restored (ha)	Year restored	Aggregated area of restoration (ha)
Bare		-	-	370
Eroded		15	2005	740
Afforested		740	2004	740
Dry vegetation types (Drained)	Mild (Wet or dry heath cover)	1073	1995	1073
	Moderate (domestic peat cutting)	900	2008	900
	Major (smooth or rough grass cover conversion)	1230	2001	1230
Cultivated	Improved grass land conversion	-	-	740
	Arable land conversion	-	-	740
Total		3958		6533

Table 2. Methane emission values and its impact on GWP at restored peatland sites.

Source	**Site**	**Quoted CH_4 figure**	**Total GWP**	**Methane GWP**
				(t CO_2e ha^{-1} yr^{-1})
(Worrall *et al.*, 2009)	Moor House (Pennines), blanket peat	5.2-6.9 Mg CH_4-C km^{-2} yr^{-1}	-20 - -91 t CO_2e ha-^{1} yr^{-1}	1.73-2.3
(Waddington & Day, 2007)	Bois des Bel, Canada (cut-over raised bog)	4.2 g CH_4 m^{-2} $season^{-1}$	+1766 g CO_2-e m^{-2} $season^{-1}$.	1.05 (14% of total C losses)
(Wilson *et al.*, 2009) (Höper *et al.*, 2008)	Cutover raised bog in the Irish Midlands	4-39 g CH_4 m^{-2} yr^{-1}	NEE: 500-2800 g CO_2 m^{-2} yr^{-1}	1.0 – 9.5 (9% of 100-year GWP at the sedge site, >28% at the reed site)
(Tuittila *et al.*, 2000)	Finland (boreal raised bog)	1.27 gCH_4 m^{-2} $season^{-1}$ (compared to 0.54 gCH_4 m^{-2} $season^{-1}$ in the unrestored peat).		0.32 (between 10% - 13% of 100-year GWP).
(Cooper *et al.*, 2012)	Migneint, Snowdonia, Wales	16 g CH_4 m^{-2} yr^{-1} (4.8 g CH_4 m^{-2} yr^{-1} before restoration)	Not calculated yet.	4.0

Table 3. Summary of costs, based upon £880 ha^{-1}.

Annual cost (£M) in:	2012	2027
"Current Aggregated"	6	5
Three-fold	17	12
Ten-fold	54	22

Table 4. Selected approved SRDP Rural Payment Options to March 2012.

Option Description	Cases with Option	Approved Funding	Funding per Case (calculated)
Buffer Areas for Fens and Lowland Raised Bogs	31	£752,158	£24,263
Management of Coastal, Serpentine + special interest heath	178	£1,642,487	£9,227
Lowland Heath	28	£405,916	£14,497
Wildlife Management on Upland and Peatland Sites	32	£806,295	£25,197
Management of Moorland Grazing	420	£3,361,028	£8,002
Moorland Grazing on Uplands and Peatlands	102	£1,753,020	£17,186
Moorland - Stock Disposal	239	£3,742,781	£15,660
Stock Disposal - combined with Moorland Grazing Options	15	£189,714	£12,648

Source: http://www.scotland.gov.uk/Topics/farmingrural/SRDP/RuralPriorities/RuralPrioritiesStats/DataOption, accessed 24 Sept., 2012

Figure 1. Annual abatement from potential peatland restoration starting in2012 at the aggregated current restoration rate and projected at this rate to 2027. Bars indicate standard deviation.

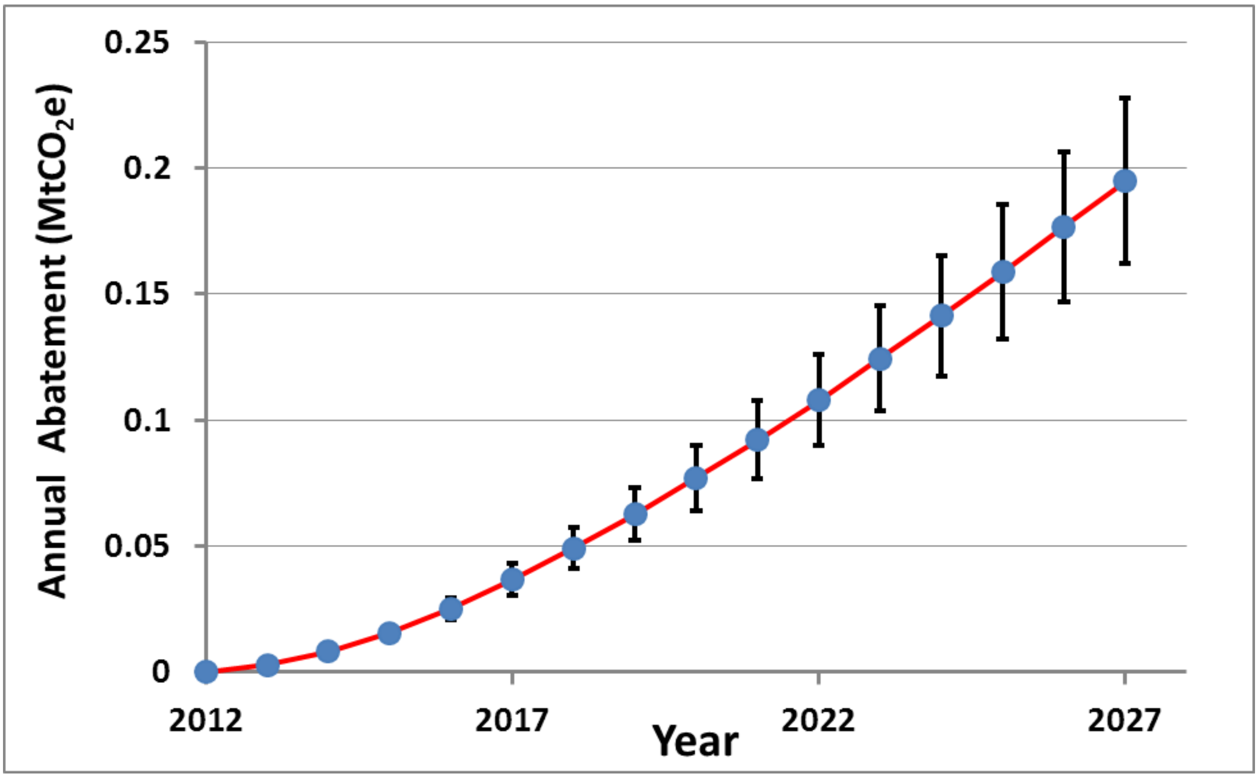


Figure 2. Cumulative abatement from all potential peatland restoration starting in 2012 at the aggregated current restoration rate and projected at this rate to 2027. Bars indicate standard deviation.

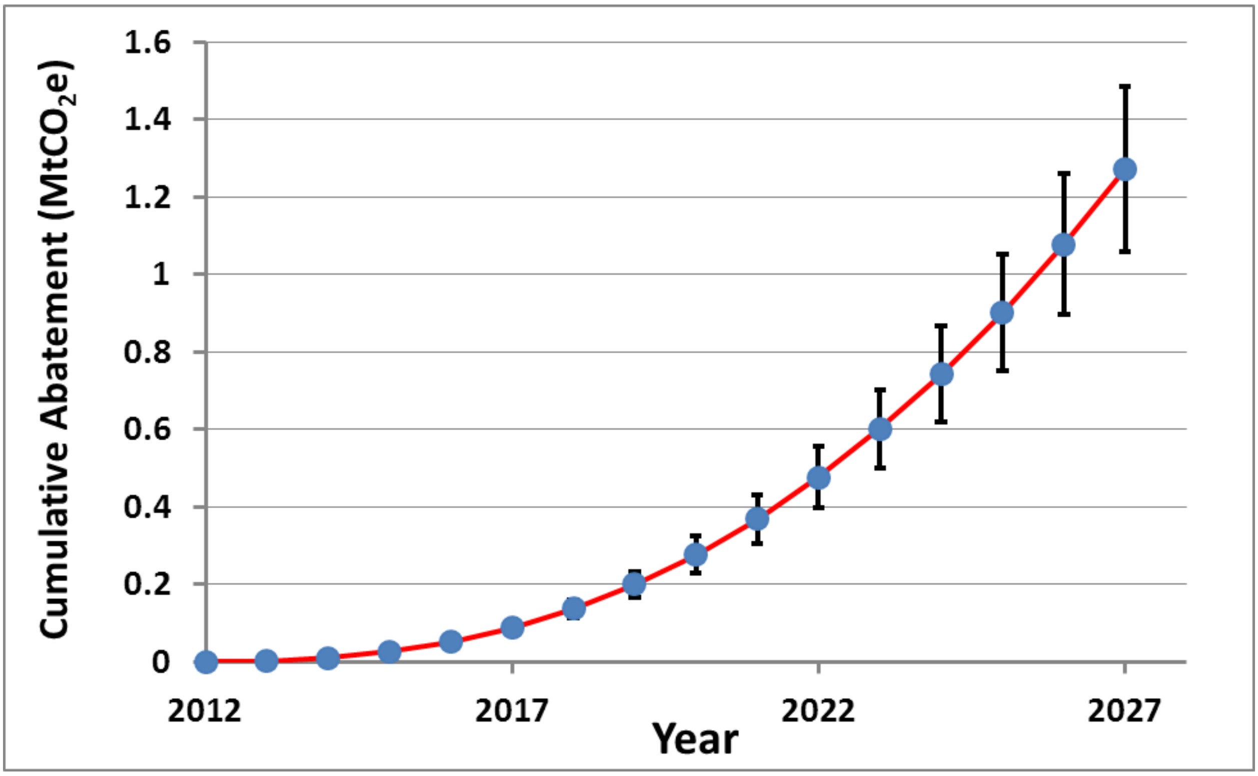


Figure 3. Annual abatement from potential peatland restoration starting in2012 at three times the aggregated current restoration rate and projected at this rate to 2027. Bars indicate standard deviation.

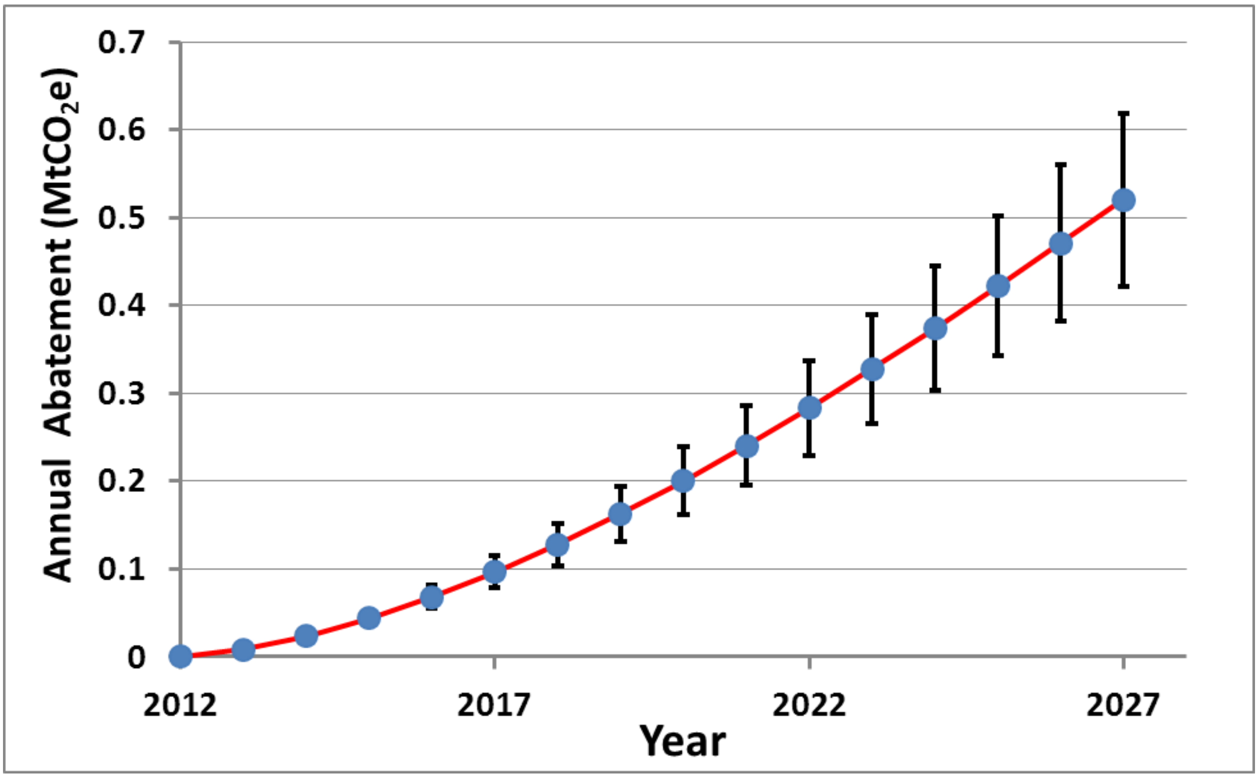


Figure 4. Cumulative abatement from all potential peatland restoration starting in 2012 at three times the aggregated current restoration rate and projected at this rate to 2027. Bars indicate standard deviation.

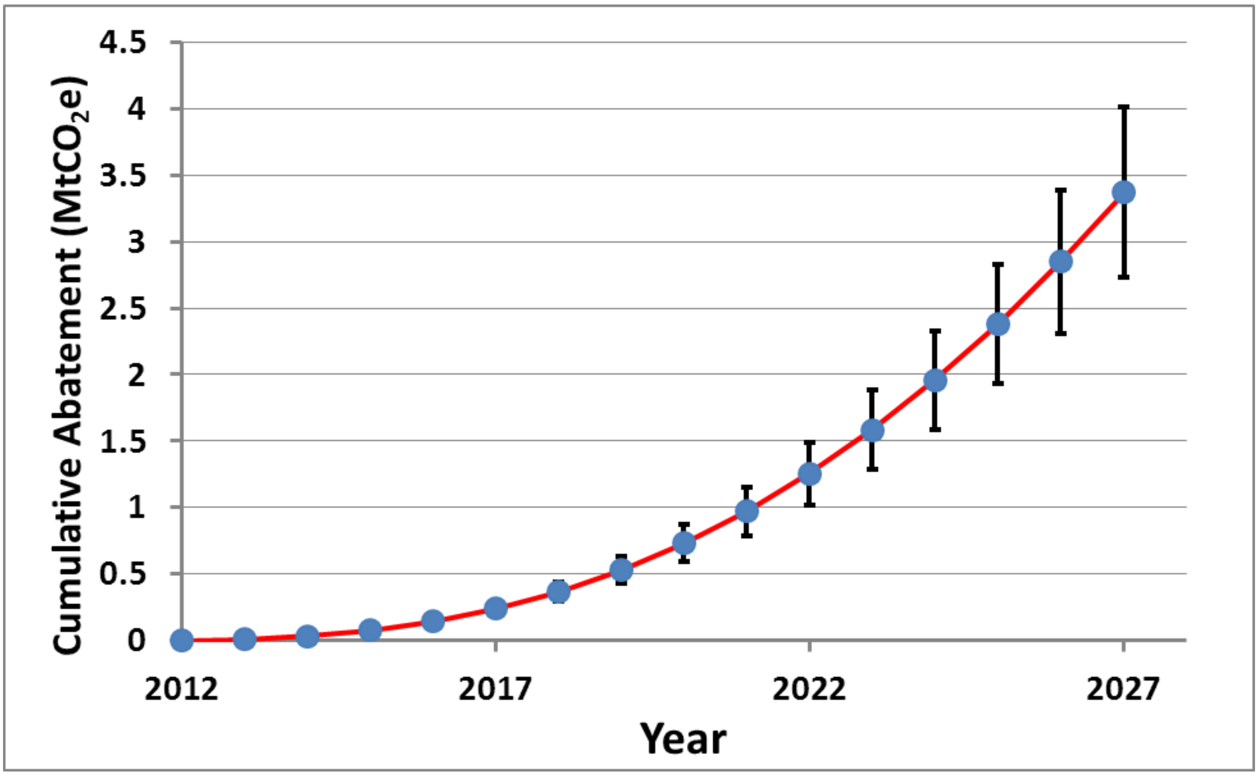


Figure 5. Annual abatement from potential peatland restoration starting in 2012 at ten times the aggregated current restoration rate and projected at this rate to 2027. Bars indicate standard deviation.

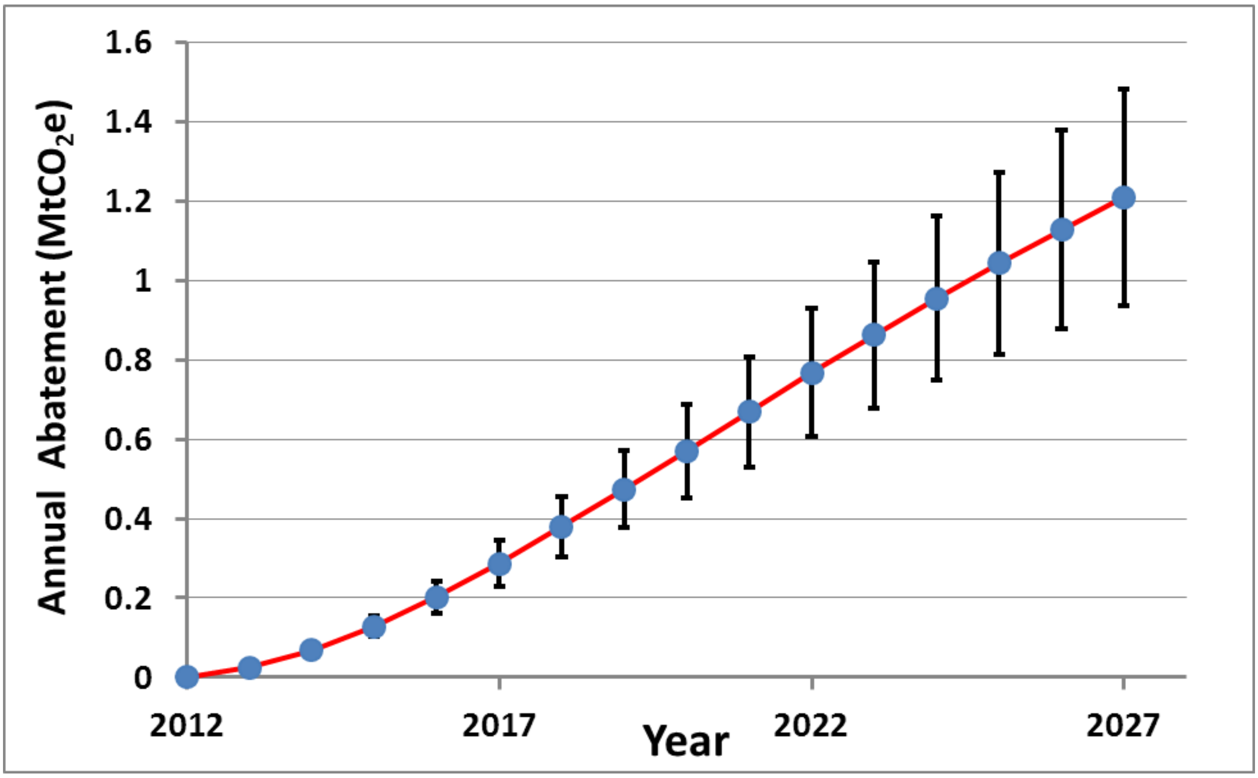
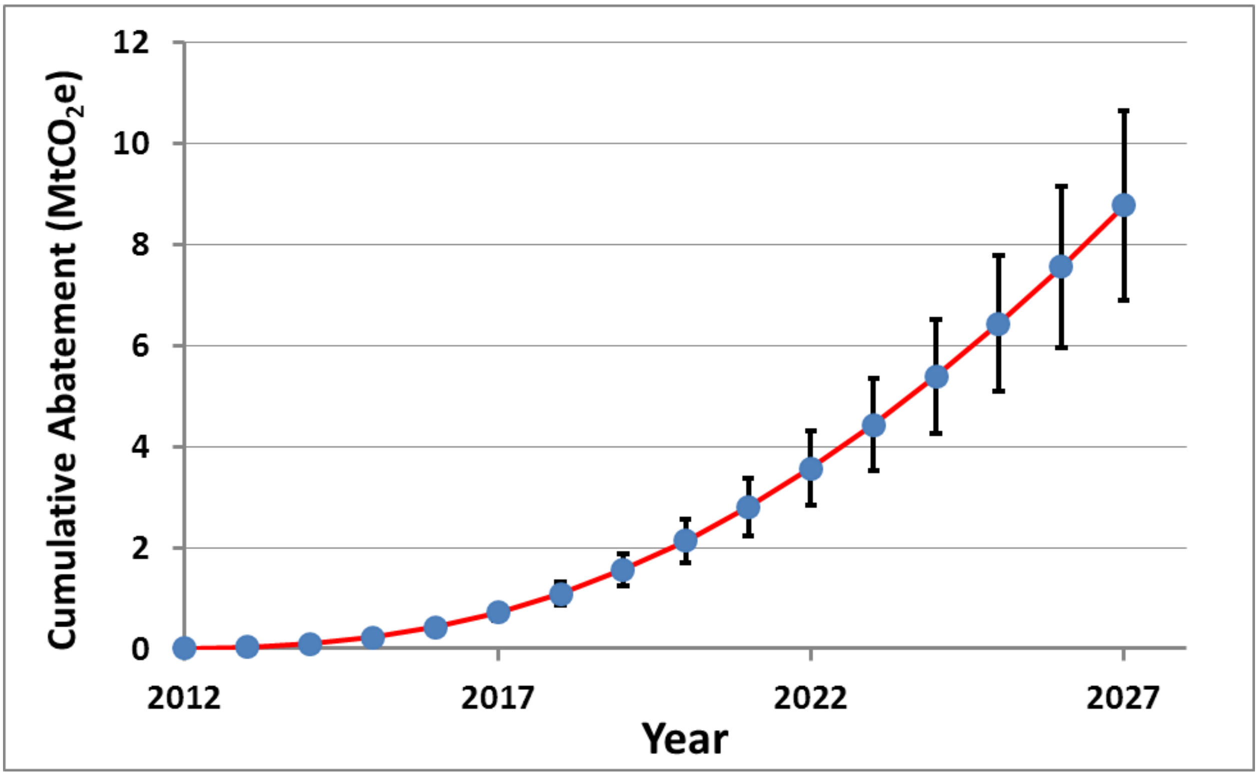


Figure 6. Cumulative abatement from all potential peatland restoration starting in 2012 at ten times the aggregated current restoration rate and projected at this rate to 2027. Bars indicate standard deviation.



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Further information

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