A Long Term Carbon Account for Forestry at Eskdalemuir.

A report for Confor by Sandy Greig, FICFor.

1. Background. In 2012 SAC Consulting was commissioned by Confor to undertake a study comparing the economic and employment effects of different land uses on hill land in the Eskdalemuir area to the north east of Langholm in southern Scotland. The forest plantations at Eskdalemuir were established in the 1970s and 1980s, and now amount to around 20,000 hectares managed by a number of different forest management companies. The productive lifespan of commercial conifers in the area is typically around 40 years and much of the forest area is at or approaching maturity.

Confor commissioned this report to augment the study by SAC Consulting. The purpose of the report is to assess the long term carbon impacts of the change of land use from upland grazing to productive co22nifer forest. To do this a “normal” forest structure has been assumed, with an equal distribution of ages of the conifer stands from 1 to 40 years old, clearfelling at 40 followed by restocking. It is likely to be 20 to 30 years before this structure is achieved on the ground, but it is a realistic ambition for the long term.

2. Assumed Forest Structure and Composition. The long term species mix and silviculture at Eskdalemuir is assumed to be as follows:

Total forest area 20,000 hectares
75% Sitka spruce Yield Class 16
5% other conifers (taken as Norway spruce Yield Class 12)
5% native broadleaves, non-intervention
15% open ground
Felling conifer crops on a 40 year rotation, no thinning

3. Aspects included in the Carbon Account. The following factors have been assessed and included in the carbon account:

- Carbon stored in above and below ground tree biomass
- Annual carbon sequestration in tree biomass
- Carbon stored in forest soils, litter and deadwood
- Annual carbon removals in harvested wood products
- Carbon stored in harvested wood products
- Carbon benefits from material substitution
- Carbon benefits from direct fossil fuel substitution (wood energy)
- Carbon emissions from forest management operations

These aspects are considered in turn in the following sections of the report. All values are given in tonnes of CO_2 equivalent (stated here as tCO_2) taking into account the 6 major greenhouse gases (GHGs).

4. Carbon Stored in Above and Below Ground Tree Biomass. Table 1 below shows the amount of carbon which would be stored at any time in the Eskdalemuir forest area.

Species	Area of Forest in Age Range (hectares)						
	0-10	11-20	21-30	31-40	41-50	Over 50	Total
SS Area	3750	3750	3750	3750	0	0	15000
tCO_2/ha	14	129	378	611	0	0	
Total tCO_2	52500	483750	1417500	2291250	0	0	4245000
NS Area	250	250	250	250	0	0	1000
tCO_2/ha	6	53	247	396	0	0	
Total tCO_2	1500	13250	61750	99000	0	0	175500
Bdls Area	100	100	100	100	100	500	1000
tCO_2/ha	7	88	280	399	441	567	
Total tCO_2	700	8800	28000	39900	44100	283500	405000
Total tCO_2	54700	505800	1507250	2430150	44100	283500	4825500

Notes: 1. All values are from the FC Carbon Lookup Tables July 2012
2. Assumes SS YC 16, 2.0m spacing, non-thin, CF at 40
3. Assumes NS YC 12, 1.5m spacing, non-thin, CF at 40
4. Assumes broadleaves SAB YC 4, 2.5m spacing, non-thin, no CF
5. Overall area 20,000 hectares, 75% SS, 5% NS, 5% broadleaves, 15% open ground

The total amount of carbon stored in tree biomass is estimated at 4,825,500 tonnes CO2.

5. Annual Sequestration in Tree Biomass. Table 2 below shows the annual sequestration of carbon in above and below ground tree biomass in the Eskdalemuir forest area. Notes are as for Table 1.

Species	Area of Forest in Age Range (hectares)						
	0-10	11-20	21-30	31-40	41-50	Over 50	Total
SS Area	3750	3750	3750	3750	0	0	15000
tCO_2/ha/annum	2.2	16.8	24.0	24.8	0	0	
Total tCO_2/annum	8250	63000	90000	93000	0	0	254250
NS Area	250	250	250	250	0	0	1000
tCO_2/ha/annum	1.0	7.0	21.6	13.2	0	0	
Total tCO_2/annum	250	1750	5400	3300	0	0	10700
Bdls Area	100	100	100	100	100	500	1000

tCO_2/ha/annum **Total tCO_2/annum**	**1.9** **190**	**13.4** **1340**	**16.6** **1660**	**10.2** **1020**	**8.3** **830**	**1.42** **710**	**5750**
Total tCO_2/annum	**8690**	**66090**	**97060**	**97320**	**830**	**710**	**270700**

The annual sequestration of carbon in tree biomass is estimated at 270,700 tonnes CO_2. Note that this is a gross figure and does not include carbon removed in harvested wood products.

6. Carbon stored in forest soils, litter and deadwood. The amount of carbon stored in forest soils depends on soil type. In most UK forest soils the soil carbon store considerably exceeds the amount stored in tree biomass. Figures from the UK BioSoil plots reported in the Forestry Commission Research Report "Understanding the Carbon and Greenhouse Gas Balance of Forests in Britain" indicates that for peaty gley and peaty podsols, characteristic of Eskdalemuir, the amount of carbon stored in the soil amounts would average **1,329 tonnes CO_2 per hectare**, excluding the litter layer. This is around 5.5 times the amount estimated to be stored in tree biomass.
The Biosoil plots indicate that the average amount of carbon stored in the litter of coniferous forests in the UK is **56 tonnes CO_2 per hectare**. (This is higher than previous estimates but is considered to be a better figure). Studies in a spruce forest on a peaty gley in NE England give a range between 26 and 110 tCO_2/hectare.
Carbon will also be stored in deadwood and coarse woody debris within the forest stands. However there are no reliable data for the amount of deadwood in upland spruce forests in the UK. The amount is likely to increase with time as best practice is now to leave more than in the past, to enhance biodiversity values. The UK Woodland Assurance Standard requires that there should be average of 20 m3 per hectare of deadwood (excluding stumps). This quantity equates to some **12 tonnes CO_2/hectare.**
Overall a reasonable estimate of the amount of carbon stored in the forest soils, litter and deadwood in the Eskdalemuir forest area is **1400 tonnes of CO_2 per hectare**, giving a total for the 20,000 hectares (excluding litter and deadwood on the 15% open ground) of **27,736,000 tonnes of CO_2.**

In comparing forestry with other land uses, the key point is not the absolute amount of carbon stored in the soil, but the change in the amount over time as a consequence of afforestation. In forestry (assuming there are no disturbances), soil C generally accumulates during forest stand development due to the input of wood and other debris. On the other hand forest management can promote the loss of soil C due to clearfelling and ground preparation for the next rotation. The 2007 study for Scottish Government (ECOSSE) concluded that "afforestation probably has little net effect on soil organic carbon stores in organo-mineral soils, but this statement is very uncertain." A more recent report by Forest Research for DECC (TRN 242/08/2011) indicates that, after a short term reduction in soil carbon following afforestation with Sitka spruce on organo-mineral soils, there is a significant increase in the amount of carbon stored in forest soils and litter over a period of several decades. However the research evidence for this is limited and for the purposes of this report it has been assumed that afforestation has no long term impact on soil carbon stores.

7. Carbon stored in Harvested Wood Products. To calculate the amount of carbon stored in harvested wood products the following assumptions have been made.

- Sitka spruce yield at clearfell (year 40) is 450m3 per hectare, 40 year rotation
- Norway spruce yield at clearfell (year40) is 350m3 per hectare, 40 year rotation
- No harvesting of broadleaves
- Harvesting yields 65% sawlogs, 15% pulp, 7.5% chipwood, 7.5% round fencing, 5% wood energy
- Sawmill sawn recovery 60%, residues 15% chipwood, 15% wood energy, 10% pulp
- Of 60% sawnwood, 70% construction, 15% sawn fencing, 15% pallets/packaging

To estimate the amount of carbon stored in wood products at any time, assumptions have to be made about the longevity of the products. The assumptions are based on Forest Research Information Note 160 (Thompson and Matthews 1989). These assumptions, the quantities of carbon added to the wood product store each year and therefore the total amount stored in the various wood products at any point in time, are shown in Table 3 below. Note that these values represent a long term equilibrium.

Wood Product	**Added to store tCO2/annum**	**Assumed Longevity Of Product**	**Total in store tCO_2**
Sawn construction timber	**43,150**	**No loss for 20 years, linear decay years 21-100**	**2,589,000**
Sawn pallets/packaging	**16,596**	**Linear decay over 5 years**	**41,490**
Wood based panels	**19,085**	**No loss for 10 years, linear decay years 11-30**	**381,700**
Fencing (round+sawn)	**14,770**	**No loss for 10 years, linear decay years 11- 30**	**295,400**
Pulp and paper	**23,788**	**Linear decay over 5 years**	**59,470**
Wood energy	**16,320**	**I year (drying)**	**16,320**
Total	**133,709**		**3,383,380**

The total amount of carbon stored in wood products from harvesting in the Eskdalemuir forest area is estimated as **3,383,380 tonnes of CO_2.** Note that this value does not include an allowance for end of life use, either through recycling, use as wood energy, or as carbon stored in wood products in landfill.

8. Carbon Benefits from Material Substitution. GHG emissions may also be reduced by using wood in place of other more energy-expensive (and therefore fossil fuel intensive) materials. This benefit of using wood products is commonly termed material substitution. There have been a considerable number of studies looking in particular at the opportunities for material substitution in construction, a relevant consideration in the UK where only a relatively small proportion of new houses are timber framed. A large meta-analysis of the GHG "displacement factor" due to wood product substitution (Sathre and O'Connor, 2010) concluded that "the substitution effect of avoiding fossil fuel emissions is ultimately much more significant than the carbon stored in wood products". This meta-analysis indicated an average emission reduction of 1.9 tonnes of CO_2 per cubic metre of wood product, assuming a dry wood density of 500kg/m3. UK grown spruce has a wood density of 340 kg/m3: using this value the emission reduction value would be 1.3 tonnes of CO_2 per m3 of wood product. This figure is reasonably close to the value, estimated by the International Institute for Environment and Development in a 2004 report, which concluded that "substituting a cubic metre of wood for other construction materials (concrete, blocks or bricks) results in the significant average of 0.75 to 1 tonne CO_2 savings." It should be noted that this benefit can only be claimed if there is a policy and demand to increase the use of timber in construction.

Assuming that all the sawn timber which goes into construction use (48,460m3/annum) has a material substitution benefit, and using the value of 1.3 tonnes of CO_2 per m3, the annual material substitution benefit for the Eskdalemuir forest area would be **63,000 tonnes CO_2.** Over 100 years the total material substitution benefit would be **6,300,000 tonnes CO_2.**

9. Carbon Benefits from Direct Fossil Fuel Substitution (Wood Energy). If wood is used to substitute for fossil fuel, GHG emissions from fossil fuel combustion are avoided. If forests regrow after harvest and re-fix CO_2 lost during woodfuel production, combustion and energy generation, a sustainable cycle of harvesting and forest regrowth continues to avoid fossil fuel CO_2 emissions and the GHG benefits continue to accrue. The potential for wood to produce direct substitution benefits is determined by the biomass productivity and the fuel conversion process.

This report uses the energy values in the FC Publication "Woodfuel Meets the Challenge" with conifer wood at 27% moisture content producing 1.39MWh per cubic metre. Assuming current lifecycle CO_2 emissions for UK fossil fuels, a reasonable estimate of the direct fossil fuel substitution benefit is that 1 m3 of wood used as a fuel saves 495 kg of CO_2.

The annual production of wood for energy at Eskdalemuir (see Section 7 above) is estimated at 8,875m3 direct plus 17,306m3 from sawmill residues. The total carbon benefit from wood energy is therefore **12,960 tonnes CO_2 per annum**. Over 100 years the total benefit would be **1,296,000 tonnes CO_2.**

10. Carbon Emissions from Forest Management, Transport and Processing. The carbon storage and substitution benefits outlined above must be netted off against the carbon emissions associated with forest management, transport and processing. A study at Kielder forest indicated that carbon emissions from forest management, harvesting, roading and timber transport amounted to around 18 kg CO_2 per m3 harvested. There is very little UK data on GHG emissions in sawmilling, data from New Zealand indicates emissions of around 180 kg CO_2 per m3 sawn, assuming kiln drying. Using these figures the total emissions from forest management (including roads), transport and processing amounts to **11,920 tonnes of CO2 per annum, or 1,192,000 tonnes of CO_2 over 100 years.**

11. Summary Carbon Account for Eskdalemuir. Table 4 below summarises the estimates from the previous sections for the 20,000 hectares of forest at Eskdalemuir. Note that the amount of carbon stored in soil, litter and deadwood has not been included as the long term impact of afforestation is assumed to be neutral – see Section 6.

Carbon Benefit	Tonnes CO_2	Comments
C stored in tree biomass	**4,825,500**	**See Section 4. Above and below ground. Sustained at this level.**
C stored in wood products	**3,383,380**	**See Section 7. Sustained at this level.**
Material substitution	**6,300,000**	**See Section 8. Benefit stated over 100 years, increases at 63,000 tCO_2/annum.**
Wood energy	**1,296,000**	**See Section 9. Benefit stated over 100 years, increases at 12,960 tCO_2/annum.**
Emissions (carbon loss)	**1,192,000**	**See Section 10. Loss stated over 100 years, continues at 11,920 tCO_2/annum.**
Net Carbon Benefit	**14,612,380**	**Over 100 years.**

The net carbon benefit from forestry at Eskdalemuir over 100 years is estimated to be **14,612,380 tonnes CO_2. This equates to 723 tonnes of CO_2 per hectare over 100 years, or 7.3 tonnes per hectare per annum.** The net benefit continues to grow at 64,040 tonnes CO_2 per annum, so after 200 years the net carbon benefit would be 21,016,380 tonnes CO_2.

12. Comparison with upland agriculture. It is important to compare the “carbon benefits” shown above with the emissions associated with a continuation of upland agriculture. Note that agricultural emissions include the GHGs methane and nitrous oxide but these have been converted to CO2 equivalance (CO_2e).
An assessment of GHG emissions from hill sheep farming in southern Scotland is given in Appendix 1 to this report. The assessment concludes that it is difficult to give a general value for GHG emissions from upland farming on the type of land that may be available for conifer forestry (e.g. Eskdalemuir). There is also uncertainty about the situations where there may be long term gains or losses in soil carbon under upland farming regimes in Scottish conditions. However there is enough evidence to suggest that upland farming in Scotland results in net GHG emissions in a range between 1 and 8 tonnes CO_2e per hectare per annum. Where farming is extensive and the livestock are predominantly or exclusively sheep emissions are likely to be at the lower end of this range.

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Appendix 1

GHG Emissions and Hill Sheep Farming in Southern Scotland

1. Purpose. The purpose of this brief note is to outline greenhouse gas (GHG) emissions from upland farming, particularly hill sheep farming, in southern Scotland. It has been commissioned by Confor to provide a comparison with the long term GHG benefits associated with productive forestry. It is not intended to be a detailed analysis of agricultural GHG emissions, but it provides an indication of the likely range of emissions and the tools currently available to individual farmers and policy makers.

2. Background. The Climate Change (Scotland) Act 2009 set a long-term target to reduce emissions of greenhouse gases (GHGs) by 80% in 2050 relative to 1990, with an interim target to reduce emissions by 42% in 2020 relative to 1990. Secondary legislation passed in October 2010 and October 2011 also set a series of annual emission reduction targets for 2010 to 2022 and 2023 – 2027 respectively. Current estimates show that emissions from agriculture and related land use were about 11 MtCO_2e in 2012, 18% of Scotland's total.

2.1. The 3 main GHGs associated with agriculture are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The sources of these GHGs, in agriculture are:

- CO_2 – produced by all animals, plants and micro-organisms during respiration. Also produced as a consequence of burning fossil fuels.
- CH_4 – formed naturally by anaerobic decay of organic matter by livestock through the digestion of feed. Also produced during manure storage and management.
- N_2O – produced during the cultivation of soil, the use of nitrogen fertilisers and animal waste handling.

Emissions from the agriculture sector as a whole are largely non-CO_2 gases, with half due to nitrous oxide and over one third (42%) due to methane.

2.2. Emissions of all GHG's can be converted to tonnes of CO_2 equivalents (CO_2e) by multiplying the mass of the GHG released by the Global Warming Potential (GWP) of each gas. The GWP is a measure of how much heat a GHG can trap in the atmosphere relative to CO_2. A GWP is calculated over a time period of 20, 100, or 500 years, but it is usual to use a 100 year time period when converting GHG emissions to CO_2 equivalents. The GWP100 figures for carbon dioxide, methane, and nitrous oxide are 1, 25, and 298, Respectively.

2.3. There is ongoing uncertainty in the emissions inventory for the agriculture, land use and forestry sector, and agriculture in particular, not just for Scotland but for the UK as a whole. This is the subject of a current research programme which will start to feed through into improvements in the accuracy of the inventory from 2013 onwards (for the devolved administrations). The UK is ahead globally on research on measuring agriculture emissions, and Scotland is taking a lead within the UK.

2.4. A general commentary on the impact of grazing on organic soils in the UK is provided by the ECOSSE (Estimating Carbon in Organic Soils – Sequestration and Emissions) report to the Scottish Government in 2007. It concludes that the effects of grazing is are dependent on livestock type and stocking density. Direct impacts on soil are caused by a combination of trampling and nutrient addition via deposition of dung and urine. Trampling effects tend to be concentrated around fence lines and feeding stations, are more pronounced with larger, heavier animals, and greater stocking densities, and are also exacerbated by wet conditions Trampling has been shown to stimulate denitrification due to reduced soil aeration and plant N utilisation and may therefore increase N_2O emissions, especially under wet conditions. Under dry conditions, trampling disturbs the soil and may act like tillage to increase aeration and stimulate decomposition and associated CO_2 emissions. Both of these effects may be amplified by the addition of nutrients. Overgrazing can cause severe degradation, not only damaging vegetation but also reducing soil organic matter and removing upper organic layers. Properly managed for site conditions however, grazing can be beneficial. There is some evidence that carefully managed grazing can aid carbon storage in organic soils. Studies of the Moorhouse NNR in the Pennines have indicated that grazed plots tend to accumulate carbon slightly faster than ungrazed areas and certainly light grazing did not cause any reduction in carbon accumulation in comparison with no grazing.

3. Carbon Footprinting and Carbon Calculators. Carbon footprinting is an important tool that allows GHG emissions arising from an organisation's activities to be quantified and benchmarked. A carbon footprint can be defined as the overall amount of carbon dioxide and other GHG emissions associated with the activities, products and services provided by an organisation. In undertaking carbon footprinting, or comparing carbon footprinting tools, it is important to be clear about the boundaries and scope of the calculations.

3.1. The **boundaries** of a calculation determine what aspect of production the calculation is assessing – whether it's a single enterprise or the whole farm; whether it takes into account operations solely within the farm gate or whether this is expanded to take into account transport and packaging beyond the farm gate for example. **Scope** defines the breadth of the data that the calculation takes into account. Within carbon calculating there are three widely recognised scopes:

- Scope 1 - direct emissions from sources that are owned or controlled by the enterprise, e.g. CO_2 emitted as a result of diesel used in tractors and farm machinery, land use change; N_2O from manure application; CH4 from enteric fermentation.
- Scope 2 – emissions associated with the generation of purchased electricity used on the farm.
- Scope 3 – indirect emissions associated with the production, processing and distribution of inputs in to the farming system, e.g. seed, bought in grain and compound feed, fertilisers, pesticides, etc. This also includes embedded emissions in machinery, building materials and farm infrastructure.

Scope 3 data is sometimes included in whole farm calculations often just in part – some calculators may factor in emissions from fertiliser production but won't factor in emissions from seed production or imported feed production and distribution. This is because it is suggested that emissions should be allocated at each level of production and distribution so that they are the responsibility of the party involved at any particular level. This means that the farmer at the end of the chain of production does not accumulate responsibility for emissions higher up the chain and is only responsible for emissions associated with their own activities.

3.2. The datasets used within the various calculators vary significantly because of differences in the quality of data used and how emissions are estimated. The **Intergovernmental Panel for Climate Change (IPCC)** has published guidelines on the methods that should be used for estimating greenhouse gas emissions by sources and removal by sinks. These guidelines are known as '2006 IPCC Guidelines' and are recognised and agreed globally. There are 3 'Tiers' of data recognised by the 2006 IPCC Guidelines:

- Tier 1 data – this data is country specific but based on global activity, it is the default factor for an emission source and contains a lower level of accuracy as figures are more general – e.g. data used for emissions from a dairy cow is universal.
- Tier 2 data – this data is country/region or farming system specific and therefore more accurate and applicable.
- Tier 3 data – this is high resolution data, possibly farm specific and is therefore the most accurate form of data.

A Tier 3 approach is the most complex level that can be used to estimate GHG emissions. It requires measurements to be taken on-farm and EF's to be calculated from this data. For example, a farmer applying a Tier 3 approach would need to measure the actual enteric methane emissions arising from his dairy herd using experimental protocols. The accuracy of GHG emissions increases with the Tier level i.e. a Tier 3 approach provides the most accurate estimation of GHG emissions. However, a Tier 2 and 3 approach requires more data which can be difficult and time consuming to obtain. On a national scale the UK uses a Tier 1 approach to report to the UNFCC.

3.3. Calculating a farm carbon footprint using the IPCC guidelines can be a complex task. The guidelines are open to differences in interpretation and because the calculations use multifaceted equations (in the case of a Tier 2 approach) there is opportunity to introduce human error. To overcome these issues a farm carbon footprint calculator can be used, of which there are several freely available via the internet that are based on the IPCC guidelines. Two carbon calculators were used for the purposes of this report: the CALM (Carbon Accounting for Land Managers) calculator and CPlan v.0. The CALM calculator was created by Natural England, Savills and the Countryside and Land Association. The calculator applies a Tier 1 approach that incorporates carbon savings generated through environmental schemes, such as Entry Level Stewardship. CPlan was especially designed for UK agricultural enterprises and use IPCC Tier 1 plus UK National data. The SAC's AgRE Calc, calculator was also tried but the results, possibly due to operator inexperience, were not reliable. Both CALM and CPlan v. 0 proved easy to use.

4. Carbon Footprinting for a Scottish Hill Sheep Farm. The CALM and CPlan v.0 tools were used to estimate the annual (2014) GHG emissions for a hill sheep farm in southern Scotland. The farm – Hillhouse Farm near Carfraemill – consists of 600 hectares between 210 and 370 metres high. It is purely a sheep enterprise with a breeding flock of 1750 ewes.

4.1. Both calculators required data on energy use (diesel, petrol, electricity), fertiliser use, livestock numbers. It was not possible to investigate the calculations and factors contained in the calculators, and this would require further research with the “owners” of the calculators. The results were as follows:

Calculator	Total GHG emissions	Per hectare
CALM CPlan v.0	1022 tonnes CO_{2e} /annum 887 tonnes CO_{2e} /annum	1.7 tonnes CO_{2e} /annum 1.5 tonnes CO_{2e} /annum

It should be noted that there are limitations with both calculators. Neither allowed an allowance for the GHG emissions associated with the production and transport of soyabean feed (the farm used 7.5 tonnes of soyabean feed in 2014) and neither allowed for the materials used in fence maintenance. It is not thought that either would add significantly to the overall GHG emissions.

4.2. The varied nature of Scottish farms means that policy based on average data may not be may not be the most appropriate approach. For example, environmental conditions can vary enormously in terms of soil characteristics, topography, temperature and rainfall. Identical activities, consequently, can generate different emission profiles at different locations. Similarly, for a given activity, management can vary in terms of, for example, livestock breeds, cultivar types or intensity of nutrient application – all of which may generate different emission profiles from identical environmental conditions. In addition the quality and digestibility of the pasture/grazing will influence emissions. However Rees et.al. (2008) considered that using simple Tier 1 IPCC emission factors modified for UK farming conditions gave robust estimates of farm scale GHG exchange which were at least as good as using more complex models.

4.3. There have been few published studies which provide data for upland farming in Scotland that can be compared with the results for Hillhouse Farm. A report on Auchenclyne Farm in SW Scotland (Stoyles 2012) gave a value for GHG emissions, using CALM, of 6.3 tonnes CO_{2e} /hectare per annum but the farm enterprise included cattle with higher associated N_2O and CH_4 emissions. Topp and Rees (2008) produced a value for GHG emissions of 3.3 tonnes CO_{2e} /hectare per annum for a livestock farm in NE Scotland. A CCW report on 20 predominantly livestock farms in the Cambrian Mountains in Wales gave values for GHG emissions ranging from 2.1 to 8.2 tonnes CO_{2e} /hectare.

5. Conclusions. The results for Hillhouse Farm are comparable with those from the limited number of other studies for upland farming in the UK, given that it is a sheep only enterprise. It is difficult to give a general value for GHG emissions from upland farming in southern Scotland, on the type of land that may be available for conifer forestry (e.g.Eskdalemuir). Further studies of individual farms, using more sophisticated calculators and the latest research evidence, would help to give a more comprehensive view. There is also uncertainty about the situations where there may be long term gains or losses in soil carbon under upland farming regimes in Scottish conditions. However there is enough evidence to suggest that upland farming in Scotland results in net GHG emissions in a range between 1 and 8 tonnes CO_{2e} per hectare per annum. Where farming is extensive and the livestock are predominantly or exclusively sheep emissions are likely to be at the lower end of this range. These values compare with the net “carbon benefits” from conifer forestry in Eskdalemuir which, averaged over 100 years, were estimated to be 7.3 tonnes CO_2 per hectare per annum.

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