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Vitae

Dr Bell is currently undertaking research into greenhouse gas emissions and mitigation from agricultural soils at SRUC. She is part of a UK DEFRA funded research project which aims to improve the national agricultural greenhouse gas inventory. Her role involves investigating the impacts of agricultural land-use on nitrous oxide emissions from soils. She is involved in quantifying the impact of different fertiliser and organic manure regimes on arable land, and the impacts of grazing animals on nitrous oxide emissions from soils. Prior to this she worked in the environmental modelling team at Aberdeen University, and completed her PhD in Earth Sciences at Durham University.

Dr Cloy is an environmental chemist currently working at SRUC – Scotland's Rural College. She undertakes research on greenhouse gas emissions and mitigation from agricultural soils. Her current research involves the investigation of different agricultural land management practices on soil carbon sequestration. Dr Cloy completed her PhD in environmental geochemistry at Edinburgh University in 2006. After her PhD she worked as a research fellow and then a temporary lecturer at Edinburgh University. Dr Cloy's research to date has addressed key scientific issues in global environmental change. Her research interests include agro-environmental science, soil biogeochemistry and environmental archives of atmospheric metal deposition.

Robert Rees is Head of SRUC's Carbon Management Centre and Professor in agriculture and climate change. He has a background in soil and environmental science, with research interests in greenhouse gas emissions and mitigation in agricultural systems. This research includes work on nitrous oxide, methane and carbon dioxide emissions from agriculture and land use. He is the Assistant Editor for the journal Soil Use and Management, and an advisor on several international research programmes.

Abstract

The agricultural sector is a significant contributor to greenhouse gas (GHG) emissions, and a growing global population means that agricultural production will remain high if food demands are to be met. Mitigation methods to reduce emissions from this sector are thus required, along with identification and quantification of emission sources, so that the agricultural community can act and measure its progress. International legislation requires the submission of annual reports quantifying GHG emissions from agriculture. The importance of attributing the correct sources of emissions to the agricultural sector is clear; however the current approach taken by the IPCC, and reported to the UNFCCC, omits emissions from soils during agricultural land-use change from its agricultural inventory.

This paper questions the IPCC approach, and the attribution of agricultural land-use change emissions to a separate category: ‘Land-use, Land-use change and Forestry’. Here a new approach adopted by the Scottish Government is examined, and compared to IPCC guidelines and national communications submitted to the Department of Energy and Climate Change (DECC) and the UNFCCC. The new Scottish Government approach attributes emissions from both land-use conversion and agricultural land under continuous use to the agricultural sector, in addition to those emissions from livestock and energy use on farms.

The extent of emissions attributed to the agricultural sector using the Scottish Government approach is much greater than that using the other approaches- largely resulting from the inclusion of cropland conversion in the Scottish Government calculations. Attribution of these emissions to the agricultural sector gives calculated emissions of 10.63 Mt CO_2eq in 2009, compared to 7.06 Mt CO_2eq using the IPCC guidelines. This has implications for the agricultural community and may influence how and if they choose to act to reduce emissions. A large reduction in emissions from cropland conversion since 1990 means that total agricultural emissions in Scotland have fallen 26.64 % when calculated by the Scottish Government, compared to a drop of only 19.13 % reported to the UNFCCC.

Keywords

Agriculture; Greenhouse gas emissions; Emission inventories; Land-use change; Carbon accounting; Scotland

1. Introduction

Livestock and arable farming play an essential role in global food production, and are economically and politically important (Herrero et al., 2011). There is pressure on the agricultural sector to produce food for a growing global population-having more than tripled since 1930 (Desjardins et al., 2007), and predicted to reach 9 billion by 2050 (Wollenberg et al., 2012). This increase in population has resulted in a 3 fold increase in cereal production and a 4 fold increase in meat production from 1960 to 2010 (Smith, 2013). More than 41 % of the European Union's land area was reported as being under agricultural production in 2007 (Firbank et al., 2013), and predictions suggest that increases in global food production of at least 50 % by 2050 will increase demands for agricultural land in Europe and elsewhere (Firbank et al., 2013). In 2009, as much as 3.1 million ha in the UK was planted with cereals. It is clear that the agricultural sector is increasing in size- but exactly how this is impacting on greenhouse gas (GHG) emissions remains uncertain, as do the opportunities for mitigation.

Within the scientific community there is increasing recognition that agriculture in general, and livestock production in particular, contribute significantly to GHG emissions (Bellarby et al. 2013; Galloway et al. 2007; Herrero et al. 2011). As a result, the global agricultural community is committed to reducing emissions to safeguard the environment; however, it must simultaneously meet the demands of a growing human population, and their increasing requirements for food high in quality and quantity. There is a need to improve the efficiency of agricultural production if we are to meet global food supply demands, and decrease agriculture's impact on climate change. Quantification of the impacts that agriculture is having on the environment is thus of major importance.

The Intergovernmental Panel on Climate Change (IPCC) recognises that increased atmospheric GHG concentrations are partly responsible for global temperature rise, and under the Kyoto Protocol industrialised countries are committed to reducing overall GHG emissions to 20 % below 1990 levels by 2020 (Franks and Hadingham, 2012). Targets in the UK are even greater, with the Climate Change Act of 2008 demanding reductions of 80 % below 1990 levels by 2050 (DEFRA, 2012). Reductions in emissions from the agricultural sector are therefore expected, as it is responsible for approximately 10-12 % of global (Crosson et al., 2011) and 9 % of UK (DEFRA, 2012) GHG emissions. There is growing consensus that we need to manage agriculture so that its impacts on climate change are restricted (Renwick and Wreford, 2011). It is also important that the methodologies used to report data are robust and provide an accurate estimate of emissions in order to allow policy makers to make informed decisions. According to Wollenberg et al. (2012), even "modest shifts" in agricultural practices can reduce emissions- but the agricultural sector needs to be aware of how and where to act. The Common Agricultural Policy (CAP) has meant that over the last two decades the extent of the UK's reported agricultural emissions has declined (although these do not reflect imported food products), as livestock numbers and nitrogen fertiliser use have been reduced (DEFRA, 2012). Even so, a contribution of approximately 9 % to total UK GHG emissions from agriculture in 2010 (DEFRA, 2012) implies that further reductions are required.

The global climate is already changing and impacting how we farm the land, the types of crops that can be grown, and future food production (Renwick and Wreford, 2011). It is vital, therefore, that the influence of agriculture on climate change is identified and portrayed to those within the sector. Although mitigation may come at a cost to the agricultural community in the initial stages, the benefits gained will limit many future potential negative climatic impacts. It is thus important that all agricultural sources of emissions are identified now, so that the agricultural industry can act to protect its future. If future climatic change results in unproductive land (Firbank et al., 2013), then it is very likely that land-use change will take place to limit the impact on overall food production. It is important then that we can gauge how this forced land-use change will impact on GHG emissions, and further affect the climate.

As part of the United Nations Framework Convention on Climate Change (UNFCCC) agreement, the UK is obliged under international legislation to submit annual reports of anthropogenic GHG emissions (Cowie et al., 2012; Misselbrook et al., 2010; Thistlethwaite et al., 2012). Submission of these inventories allows key sources of pollution to be identified and highlighted to the public and policy makers. Inventories can help guide where to focus mitigation efforts and assess how effective they are over time. But if these are not accurate, transparent and easily interpreted, we may miss the opportunity to undertake effective mitigation (Ellison et al., 2011; Herreco et al., 2011; Wang et al., 2011). Inventory quality was identified as an important issue by the IPCC in 1996 (Lim et al., 1999) and the case study described here will use and compare results from three different inventory approaches to illustrate that improvements could still be made.

2. Objectives

Before identifying changes we can make to reduce GHG emissions we need an accurate GHG emission baseline inventory. Without this we cannot target the changes that need to be implemented, and in which sector, to gain maximum benefit. The UNFCCC requires that all signatories use a comparable methodology to report their national emission inventory (Brown et al., 2001). It is widely accepted that global climate change is a challenge to be addressed but firstly the link between agriculture and climate change must be assessed and presented accurately and consistently. Flaws in the assessment of agriculture's contribution will lead to dispute, failure to trust the science, and consequently, failure to act. Global recognition of the extent of agriculture's contribution to GHG emissions is required, as is quantification of how its contribution compares to that of other emission sources.

Although many nations have attempted to quantify and pin-point their GHG emission sources, uncertainties remain, and improvements in the methodologies used are regularly reported. The extent to which IPCC reporting guidelines identify, describe and quantify agricultural emissions is critical for effective mitigation. This paper will address this issue by comparing different reporting metrics and evaluating their role in mitigation policies. The aim here is to highlight the different methods available to calculate/report national agricultural GHG emission inventories, the variation in outputs produced, and the problems and challenges this can cause. Outputs produced by different methodologies could influence how the agricultural community will act and respond to a changing climate and their impacts upon it. Here we show how the use of different inventory and accounting methods can skew interpretation of the agricultural sector's performance in meeting obligations to reduce emissions. Scotland has adopted a novel approach to producing its inventory, and Scottish agricultural GHG emission calculations will be used here as a case study. Scotland's total GHG emissions in 2009 and 2010 have been calculated by the Scottish Government and related to emission sources (The Scottish Government, 2011). This study will use these calculated emissions and attribute them to specific sectors using either: 1. The new Scottish Government approach; 2. The sectors outlined in IPCC accounting guidelines, or 3. Sectors used in national communications to the UK Department of Energy and Climate Change (DECC) and the UNFCCC. The extent of the emissions attributed to agriculture using the three approaches will then be compared. Each approach uses emissions calculated and provided directly by the Scottish Government, and then reallocates these numbers to the respective sectors used in each approach, as outlined in Annex D of The Scottish

Government's Greenhouse Gas Emissions 2009 Report (The Scottish Government, 2011) and Section 3.1.

In the UK, agriculture is a devolved responsibility, with a different policy approach being adopted by each of the devolved administrations (DEFRA, 2012). If countries take different approaches, and include and dismiss practices and sources in their agricultural inventories, there is the danger of not comparing 'like for like' GHG emissions when assessing a countries performance in meeting targets. It is hoped that the Scottish example will illustrate the problems of segmentation in GHG inventories. A comparison then will be made of how reported emission reductions from agriculture in other UK and EU countries will differ if they use the Scottish Government approach as an alternative to that used in national communications when reporting to the UNFCCC. The major focus will be on the sectorial approach to accounting, and the attribution of emission sources, with consideration then given to further improving a country's agricultural GHG emission inventory. Attention will be paid to the importance and difficulty involved in estimating land-use and land-use change impacts on soil carbon, and issues involving source and end-user emissions.

3. Scotland: A case study

Scotland has set its own GHG emission reduction targets, in addition to those set by the UK, and is committed to reducing its 2006 GHG levels by 80 % by 2050, and achieving a 42 % reduction by 2020 (Renwick and Wreford, 2011). The implementation of Scotland's Climate Change Act (2009) has meant that all sectors must act now to meet these reduction targets, with a clear expectation that all sectors including land-use will contribute to GHG mitigation (Feliciano et al., 2013). The land use strategy for Scotland formed following implementation of the Climate Change (Scotland) Act 2009, and makes specific reference to the requirement to reduce agriculture and agricultural land-use emissions by 2020 (Feliciano et al., 2013).

The various ways in which GHG emissions from Scotland's agricultural sector are calculated are reported in Section 3.1. Emissions attributed to the agricultural sector in the years 2009 and 2010 using each approach will be compared. Under the Scottish Government approach, agriculture and related land-use are combined, and thus emissions from agriculture include net CO_2 emissions from agricultural land-use, and agricultural land-use change in addition to those from livestock and production. These land-use emissions are not currently accounted for in the *agricultural* inventory for England, where the focus is on emissions from agricultural *production.*

3.1. Scotland: Inventory methodologies

3.1.1. IPCC guidelines for accounting

The 1996 IPCC inventory guidelines require emission reporting from the following six categories: *Energy*; *Industrial Processes*; *Solvent and other product use*; *Agriculture*; *Land-use change and forestry (LUCF)*; *Waste* (Crosson et al., 2011). These categories were revised in the 1996 revised guidelines, where *LUCF* was expanded to include emissions/sequestration from land under continuous use. The new category *Land-use, land-use change and forestry (LULUCF)* was thus created (Paustian et al., 2006). In the 2006 IPCC guidelines the categories have been altered and amalgamated, with only four sectors to which GHG emissions are now attributed. The *Agriculture* and *LULUCF* sectors were combined to produce the sector *Agriculture, forestry and other land-use (AFOLU)* (Crosson et al., 2011). Regardless of which IPCC guidelines are followed, one noticeable feature of the accounting system is the isolation of land-use and land-use change (in the earlier guidelines), or the amalgamation with other sectors in the 2006 guidelines, making the source and cause of these land-use emissions difficult to decipher. Even though emissions from agricultural soils are accounted for in the IPCC agricultural inventory guidelines, these only relate to emissions of N_2O (MacCarthy et al., 2010). This refers to direct N_2O emissions from agricultural soils and agricultural soils used for livestock production, as well as in-direct emissions from nitrogen used in the agricultural sector. There is no accounting of CO_2 emissions from agricultural soils- be it from land under continuous use, or undergoing land-use change. All sources of GHG emissions ascribed to the agriculture sector under the revised 1996 IPCC guidelines are displayed in Table 1.

3.1.2. National communication reports

The devolved nations of the UK are commissioned by the DECC to submit annual inventories in national communication format, where *Agriculture* is separate from *LULUCF* (Thistlethwaite et al., 2012). Although similar, there is a noticeable difference between national communication reports to the DECC and UNFCCC and those using IPCC guidelines- being the inclusion *of Fuel and Agrochemical Use* within the *Agriculture* sector (Table 1).

3.1.3. Scottish Government approach

New categories created by the Scottish Government when reporting Scotland's total GHG emissions are described in The Scottish Greenhouse Gas 2009 Emissions Report (The Scottish Government, 2011) and displayed in Table 2. All seven sectors differ to those listed in the IPCC guidelines, with inventories calculated for: *Business and Industry*; *Transport*; *Residential*; *Waste Management*; *Development (land use change)*; *Agriculture and related land-use*; and *Forestry*. The Scottish Government have combined net emissions from the IPCC *Agriculture* sector with those from other IPCC sectors that they believe should be classified as agricultural emissions (Table 3). This approach was taken so that emissions/sequestration associated with converting grass to cropland and vice versa could be included within accounting from the agricultural sector. It was decided that fuel and chemical use in agricultural machinery and processes should also be accounted in the agricultural inventory if a true representation of the sector's emissions was to be presented. Emissions from the *Agriculture and related land use* sector include some of those from the IPCC sectors *Energy*, *Industrial Processes*, *Agriculture*, and *LULUCF.* The IPCC revised 1996 guidelines account for much fewer sources of emissions within the *Agriculture* sector than the Scottish

Government (Table 1). Interestingly, none of the emissions attributed by the Scottish Government to *Cropland Conversion* in the *Agriculture and related land-use* sector are included in the IPCC inventory guidelines for *Agriculture*, with many of the emissions attributed by the Scottish Government to *Soils* (within the *Agriculture* sector), also dismissed (Table 1). The Scottish Government *Cropland Conversion* category includes those emissions that are ascribed to the following IPCC categories under LULUCF: *Land converted to cropland*; *land converted to grassland*; *N_2O emissions from disturbance associated with land-use conversion to cropland*. Eight of the detailed emission sources attributed to the *Agriculture and related land-use* sector by the Scottish Government are assigned to the *LULUCF* sector in the IPCC guidelines, whilst a further four are assigned to the *Energy* sector, and the remaining source (agrochemical use) to *Industrial processes* (Table 3). The remainder of the *LULUCF* sector has been reclassified into: *Forestry*, and *Development* (The Scottish Government, 2011).

Although the Scottish Government accounting system means that emissions from agricultural land under continuous land-use are accounted and attributed to the agriculture sector, the use of emissions calculated following the IPCC guidelines means that some forms of CO_2 emissions/sequestration are still omitted (e.g. sequestration in organic soils).

3.2. Scotland's emissions: Results

3.2.1. Scotland: agriculture's contribution to total GHG emissions 2009

3.2.1.1. Scottish Government Approach

Scotland emitted a total of 50.95 Mt CO_{2eq} in 2009, with *Agriculture and related land-use* responsible for 10.63 Mt CO_{2eq}, making it the third largest source after *Business and Industry* (25.76 Mt CO_{2eq}), and *Transport* (13.58 Mt CO_{2eq}) (Fig.1). Net emissions to the atmosphere from *Agriculture and related land-use* were greater than those from: *Residential*, *Waste Management*, *Development*, and *Forestry* sectors, with *Forestry* being the only carbon sink (9.97 Mt CO_{2eq}). Of the total net emissions in 2009, the *Agriculture and related land-use* sector was responsible for 18 % of emissions.

3.2.1.2. IPCC Approach

Although total GHG emissions from Scotland calculated using this approach are the same as those using the Scottish Government approach, net emissions from *Agriculture* totalled only 7.06 Mt CO_{2eq} in 2009, and it was the second largest source category after *Energy* (43.08 Mt CO_{2eq}). Emissions from *Agriculture* contributed 12 % towards total net GHG emissions, and were greater than those from *Waste* (2.07 Mt CO_{2eq}), *Other* (2.83 Mt CO_{2eq}), and *Industrial Processes* (1.56 Mt CO_{2eq}) (Fig.1).

The extent of the emissions attributed to the agricultural sector using Scottish Government and IPCC methodologies differ as a result of net emissions and sequestration from each sector (Fig. 1). Differences in the size of the carbon sink attributed to forestry and land-use activities depends on the inventory approach taken, with net sequestration in the IPCC *LULUCF* sector being smaller than that in the Scottish Government *Forestry* sector, due to emissions associated with cropland conversion. The contribution of agriculture to Scotland's total net GHG emissions in 2009 using the three alternative (Scottish Government, IPCC, and national communications) inventory approaches is shown in Fig.2.

3.2.2. Scotland: emissions from the agricultural sector 2010

3.2.2.1. Scottish Government Approach

In 2010 a net total of 10.46 Mt CO_{2eq} was reported to be emitted from the category *Agriculture and related land use* in Scotland. Of this, *Soils* contributed 4.43 Mt CO_{2eq} (42 %); *Fuel and agrochemicals*, 0.81 Mt CO_{2eq} (8 %); *Cropland conversion*, 2.00 Mt CO_{2eq} (19 %); *Livestock: manure storage*, 0.57 Mt CO_{2eq} (6 %); and *Livestock: enteric fermentation*, 2.66 Mt CO_{2eq} (25 %).

3.2.2.2. IPCC Approach

Use of the IPCC guidelines to calculate agricultural sector emissions would suggest that 7.14 Mt CO_{2eq} was emitted to the atmosphere in 2010. Of this, S*oils* contribute 3.91 Mt CO_{2eq} (55 %), *livestock: manure storage* contributes 0.57 Mt CO_{2eq} (8 %), and *Livestock: enteric fermentation* makes up the remaining 2.66 Mt CO_{2eq} (37 %).

3.2.2.3. National communications

If total GHG emissions from the agriculture sector in 2010 are reported using the national communications format, the largest contributor is again *Soils* (3.91 Mt CO_{2eq}, 49 %). *Livestock: enteric fermentation* contributes 2.66 Mt CO_{2eq} (34 %), *Fuel and agrochemical use* contributes 0.81 Mt CO_{2eq} (10 %), and the remainder of the emissions originate from *Livestock: Manure storage* (0.57 Mt CO_{2eq}, 7 %).

The difference in size of net emissions attributed to different sources using alternative approaches is displayed in Fig.3. The extent of net emissions resulting from cropland conversion is also displayed, revealing the degree to which the agricultural community could be swayed towards specific emission reduction strategies- depending on which inventory approach they adopt.

3.2.3. Scotland: Agriculture emissions since 1990

Comparison of the size, extent, and trend in emission reduction over time using the 3 approaches is displayed in Fig.4. Total GHG emissions from the Scottish agricultural sector have fallen from 14.26 Mt CO_{2eq} in 1990, to 10.46 Mt CO_{2eq} in 2010 when emission trends are measured using the Scottish Government inventory sectors. This represents a 26.6 % decrease in emissions from agriculture. When corresponding emission trends are analysed under IPCC and national communication approaches there is a decrease of approximately 19 % from 1990 to 2010 (Fig.4).

Although there is a reduction in Scotland's agricultural emissions over the time period 1990-2010 using all three different inventory approaches described above, the extent of the reduction appears greater when using the Scottish Government approach. The extent of the reduction from livestock and soils is very similar using all three approaches (Fig.5), but *Cropland Conversion* has demonstrated the greatest reduction in net emissions (from 3.98 Mt CO_{2eq} to 2.0 Mt CO_{2eq}). The inclusion of *Cropland Conversion* emissions in Scotland's *agricultural* inventory is thus responsible for the Scottish Government inventory approach revealing the largest drop in total agricultural emissions (Fig.5).

4. Discussion

The novel approach adopted by the Scottish Government in calculating Scotland's GHG emission inventory has revealed the extent to which the performance/failure of different sectors in achieving reduction targets can be masked or revealed depending on how the sources of all major GHGs are categorised. Use of the Scottish Government approach to calculate agriculture's contribution to total Scottish GHG emissions in 2009 reveals 6 % greater emissions than when following IPCC guidelines. The figure of 12 % calculated using IPCC guidelines would generally agree with the approximately 10 % contribution from agriculture to UK (DEFRA, 2012) and global (Crosson et al., 2011) GHG emissions. The 18% contribution to total emissions calculated using the Scottish Government approach is however much greater, suggesting that alterations to these globally accepted figures may be necessary if the extent of agriculture's *true* contribution is to be revealed.

Specific reference to emissions from the agricultural sector in Section 3.2.2 reveals the main contributors to emissions from this sector, identifying cropland conversion as a major source, which is not included in national communications or using the IPCC approach. If cropland conversion and rotational systems continue to be categorised and accounted under the *LULUCF* sector there is potential for wide scale alterations in pasture and arable land-use, with no accounting of the associated emissions attributed to the agricultural sector. Although attribution of these emissions to the agricultural sector does not necessarily mean an increase in available methods to reduce them, it may provide increased awareness of the impact that agricultural activities are having on the environment when agricultural emissions are reported, potentially providing the agricultural community with greater incentive to change the way they manage land. Assessment of the performance of Scotland's agricultural sector in reducing its 1990 emissions could also vary greatly depending on which inventory approach is used. This could have major implications when comparing Scotland's performance with the 2020 target of a 10 % reduction in total GHG emissions from agriculture set by the Scottish Government (The Scottish Government, 2010). The 26.64 % reduction since 1990 calculated using the Scottish Government approach suggests that these targets are being met and surpassed to a greater extent than would be assumed if the achievements were compared to the 19.13 % reduction reported in national communications. As identified in Section 3.2.3, it is a reduction in emissions from cropland conversion that is responsible for the much larger reduction in emissions reported in the Scottish Government approach, implying that this should be where future GHG emission reduction and mitigation efforts should be focussed if the trend is to continue. For the true performance of the agricultural sector's attempts to reduce its impact on climate change to be revealed it appears that the Scottish Government approach should be followed, and that cropland conversion should be ascribed to this category.

Use of the Scottish Government approach in the rest of the UK, and the EU-15 and EU-27 would also influence interpretation of how the agricultural sector is performing in these countries, and whether they are achieving any agricultural emission reduction targets that they may have set. Much greater reductions in 1990 agricultural emissions are calculated from all countries of the UK using this approach when compared with the accounting system used in national communications (Table 4). Only slight differences in the performance of the EU-15 and EU-27 countries would however result, although the size of the emissions from these EU countries would be much larger if the agricultural sector included emission sources attributed by the Scottish Government (Table 4).

4.1. Problems with the sectorial approach to emissions accounting

Results from the Scottish case study presented in Section 3 suggests that whether the agricultural community's attempts to meet reduction targets will be viewed as successful depends on the sector to which its emissions are attributed. It is clear that attributing emissions to the incorrect sources will skew the perceived achievements of the agricultural sector. Research undertaken by Crosson et al (2011) describes and accounts for the main components of agricultural emissions "outside of land-use change", but by omitting this vital source of GHGs we are at risk of obscuring emissions from those who could implement change. As shown in Table 1, the IPCC method for calculating a nation's agricultural inventory will mean that only those emissions from activities associated with soils (N_2O emissions), and livestock (enteric fermentation, manure storage) will be attributed to the agricultural sector. This could limit who and what will be targeted in emission reduction policies, and there is potential for a lack of recognition regarding the extent of the agricultural sector's contribution. Available options for the agricultural sector to reduce emissions will then be limited. This could have wide-ranging and potentially critical impacts as we enter into a time of uncertainty, population growth, and climate change. With global food demand increasing there is concern over whether food supply can be maintained or increased if agricultural GHG emissions are to be reduced. A problem arises depending on what we consider to be agricultural emissions. Methods currently considered in attempts to reduce GHG emissions and increase global food supply whilst maintaining biodiversity include: converting to reduced meat or vegetarian diets; mixed cropping; cultivation of shelter belts (Hicks et al., 2012; Smith, 2013); and agricultural extensification (Leifeld and Fuhrer, 2005). The need to quantify potential impacts on GHG emissions from agricultural land-use change is essential, as is the attribution of them to the agricultural sector. If emissions from land-use change are not considered as agricultural emissions, but instead attributed to *LULUCF*, then those in the agricultural sector could plough up grasslands for crop production (reducing emissions from grazing animals and providing food for vegetarian diets) and incorrectly assume that they are contributing to GHG reduction targets. If emissions from energy and fuel resulting from this land-use change did not offset reductions from livestock emissions there is a strong possibility that this agricultural land-use change may reduce those GHG emissions attributed to *agriculture,* whilst increasing crop growth and food supply. This would imply that food supplies can increase alongside a reduction in GHG emissions from agriculture, but this *may be* at the expense of increased emissions of CO_2 from soil carbon (which are accounted under *LULUCF*). Considering the size of the global soil organic carbon (SOC) pool (approximately 1500 Pg, second only to that of the ocean's carbon store (Cloy et al., 2012; Stockmann et al., 2013)) and the fact that agricultural activities have the potential to emit or sequester large amounts of SOC (Cloy et al., 2012; Dawson and Smith, 2007; Smith, 2008) it is vitally important that the agricultural community are aware of how their activities influence the size of this carbon reservoir before such options are encouraged. Although SOC losses or gains from agricultural land-use and land-use change are estimated, they are not accounted as *agricultural* emissions in national communications and IPCC guidelines, but instead as emissions from *LULUCF*. This seems odd considering the major role SOC is given in discussions by Ceschia et al. (2010) and Stockmann et al (2013), and the large gains and losses in SOC that can result from *agricultural* land-use change into and out of arable and pasture land (Guo and Gifford, 2002; Post and Kwon, 2000), and emissions from agricultural land under continuous use. In their introduction on the impacts of agriculture to GHG emissions, Ceschia et al. (2010) discuss the sources of agricultural emissions, with an emphasis on soil carbon disturbance. This is emphasised further by Rounsevell and Reay (2009), who discuss both the effects of agricultural land-use change, and also arable tillage practices on emissions of CO_2 from soil disturbance. Agricultural land-use and land-use change can clearly influence the GHG source/sink capacity of soil (Smith et al., 2007a). Firbank et al (2013) report a reduction of approximately 20 % in UK agricultural emissions between 1990 and 2008- but if this has not included SOC emissions or sequestration from agricultural land-use change, which instead have been accounted elsewhere, then it could create a false impression. The fact that conversion of grasslands to agricultural land can release "considerable" amounts of CO_2 (Lesschen et al., 2011), and that as little as a 10 % decrease in the SOC pool would equate to 30 years of anthropogenic carbon emissions

(Stockmann et al., 2013) makes it surprising that the link between soil carbon and agricultural activities is not highlighted to a greater extent in *agricultural* inventories. In the UK, it is reported that agriculture is responsible for 62 % of total N_2O emissions, 37 % of total methane (CH_4) emissions, and 1 % of total CO_2 emissions (Defra, 2010; Franks and Hadingham, 2012; Smith et al., 2007c). Read in isolation, this implies that the focus should be on reducing the non-CO_2 emissions. But this could be misleading, given that this 1 % does not include agricultural emissions from SOC. There is the potential for land-use and management change to be made without regard to the consequences of CO_2 emissions. In a similar manner, statements such as "All on-farm CO_2 emissions come from on-farm energy use" (DEFRA, 2011) could also be misleading. When discussing emissions from the agricultural sector, Hillier et al. (2011) report that soil disturbance leads to losses of CO_2. It is clear that different authors and approaches are un-decided on what should be attributed to agriculture, and that if the correct sector is not credited with the positive impact that it has produced, then there is the risk of a reduced incentive to act in the future (Cowie et al; 2012; Ellison et al., 2011). Similarly, if the correct sector is not recognised as being responsible for emissions, then encouragement to reduce emissions will be targeted in the wrong places.

4.2. Improvements to the Scottish Government approach: The impact of land-use on SOC, and source/end-user emissions

Although the Scottish Government approach to agricultural emissions accounting includes emissions and sequestration associated with agricultural land-use and agricultural land-use change, the IPCC guideline methods used to calculate these emissions could potentially be improved. Allocating these net emissions to the agricultural sector creates a much clearer picture of those originating from agriculture; however the emissions attributed to these changes in land management still follow IPCC guidelines. Accounting for SOC loss/gain under land in continuous use or undergoing change poses many difficulties (Smith et al., 2012), with much dispute evident in the literature. Many studies report changes in SOC stocks following a change in agricultural land-use, with arable soils being depleted in carbon compared to temporary and permanent grassland (Bell and Worrall, 2011; Bell and Worrall, 2010; Bradley et al., 2005; Smith et al., 2000). The extent of the emissions or sequestration associated with land-use change is still largely uncertain, as is the length of time over which soils continue to emit or sequester CO_2 following this change (Freibauer et al., 2004; Poeplau and Don, 2013; Reijneveld et al., 2009). Focus then, to further improve agricultural GHG emission inventories, should not only be on attributing the correct emission sources to this sector, but also on trying to achieve a better estimate of the extent of these emissions and the timescale over which they persist.

In relation to the Scottish case study, an important issue concerns the IPCC guidelines suggestion that only emissions (no sequestration) will occur from grasslands remaining grasslands when situated on organic soils. This issue is very pertinent in Scotland as peatlands here are estimated to cover an area of 2500 ha (Trinder et al., 2008), and contain a carbon stock estimated at 4.5 billion tonnes (Smith et al., 2007b). The IPCC guidelines adopt a different approach to grasslands remaining grasslands on mineral soils. For a mineral soil it is assumed that the SOC stock under a grassland remaining grassland can grow or shrink as a result of either sequestration or emissions of CO_2 resulting from land management activities. Recent studies into the management of peatlands under agricultural land-use do, however, suggest that gains in SOC are possible, implying that sequestration should also be accounted in the IPCC guidelines when those land management practices are undertaken on organic soils. Worrall et al. (2010) suggest that sequestration of carbon will take place in grasslands remaining grasslands on organic soils when drain-blocking, revegetation, grazing removal, and the cessation of managed burning are implemented. Although research into the impact of sheep grazing regimes is limited, there are suggestions that changes to stocking rates and the presence or absence of sheep grazing on peatlands can result in a reduction in emissions, and potentially also an increase in carbon sequestration (Clay and Worrall, 2013). There is also the potential for grasslands with organic soils to sequester carbon if their vegetation is restored following degradation caused by wildfires (Worrall et al., 2011).

Two further issues still under debate concern the attribution of emissions to source or end-users following the removal of woodland and forests to accommodate agricultural land, and the reallocation of other sources in all other sectors to maintain consistency in the methodology. In relation to source or end users this raises the question- should deforestation for agricultural use also be included within the agriculture sector when calculating an emissions inventory? With this included the 10-12 % contribution by agriculture to total global GHG emissions quoted by Hillier et al. (2011) increases to 17-30 %. This indicates the importance of having a uniform consensus on where these emissions should be ascribed. In addition, the end use of the products from deforestation must also be accounted, suggesting that further work on complete life cycle assessment is required to gain a true picture of agriculture's contribution to GHG emissions. In relation to the issue of reallocation of sources in all other sectors- there are still potential improvements to be made. Although the Scottish Government has taken large steps in implementing this process (see Annex D, The Scottish Government, 2011) further change could be made once the current methodology has been assessed.

5. Conclusion

Use of the Scottish Government approach in calculating an agricultural inventory has shown how the performance of this sector's attempts to reduce their impacts on global climate change will be evaluated compared to other methods used in reporting emissions to the UNFCCC. More thorough investigation into the way we account for emissions from agriculture is needed now, so that emissions are not obscured if wrongly attributed to a different sector. It is vital that the correct emissions are attributed to the correct sector; otherwise the incentive to act will be missed. Although the original 1996 IPCC inventory guidelines have recently been updated, with new categories created, would it not be better for other countries to take a similar approach to that of the Scottish Government? Only by attributing agriculture and its related land-use and land-use change to its own category will we present a true picture of total emissions from this sector.

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Figure captions

Fig. 1. A comparison of the extent of Scotland's 2009 net emissions/sequestration (Mt CO_2eq) from different sectors depending on the inventory approach used.

Fig. 2. The contribution of agriculture to Scotland's total net GHG emissions in 2009 using 3 alternative approaches (NC: National Communications; SG: Scottish

Government) to inventory production. Numbers on bars indicate emissions in Mt CO_2eq.

Fig. 3. The sources and extent of Scotland's agricultural emissions using different approaches to inventory formation (NC: National Communications; SG: Scottish Government).

Fig. 4. The extent of the reduction in Scotland's agricultural emissions from 1990 to 2010. The IPCC sectorial approach would imply a 1.67 (19.0 %) drop in emissions, the NC inventory would imply a 1.88 (19.1 %) drop in emissions, and the SG approach would imply a 3.80 (26.6 %) drop in emissions. (NC: National Communications; SG: Scottish Government).

Fig. 5. The change in Scotland's agricultural emissions (Mt CO_2eq) from different emission sources: 1990-2010. (NC: National Communications; SG: Scottish Government).

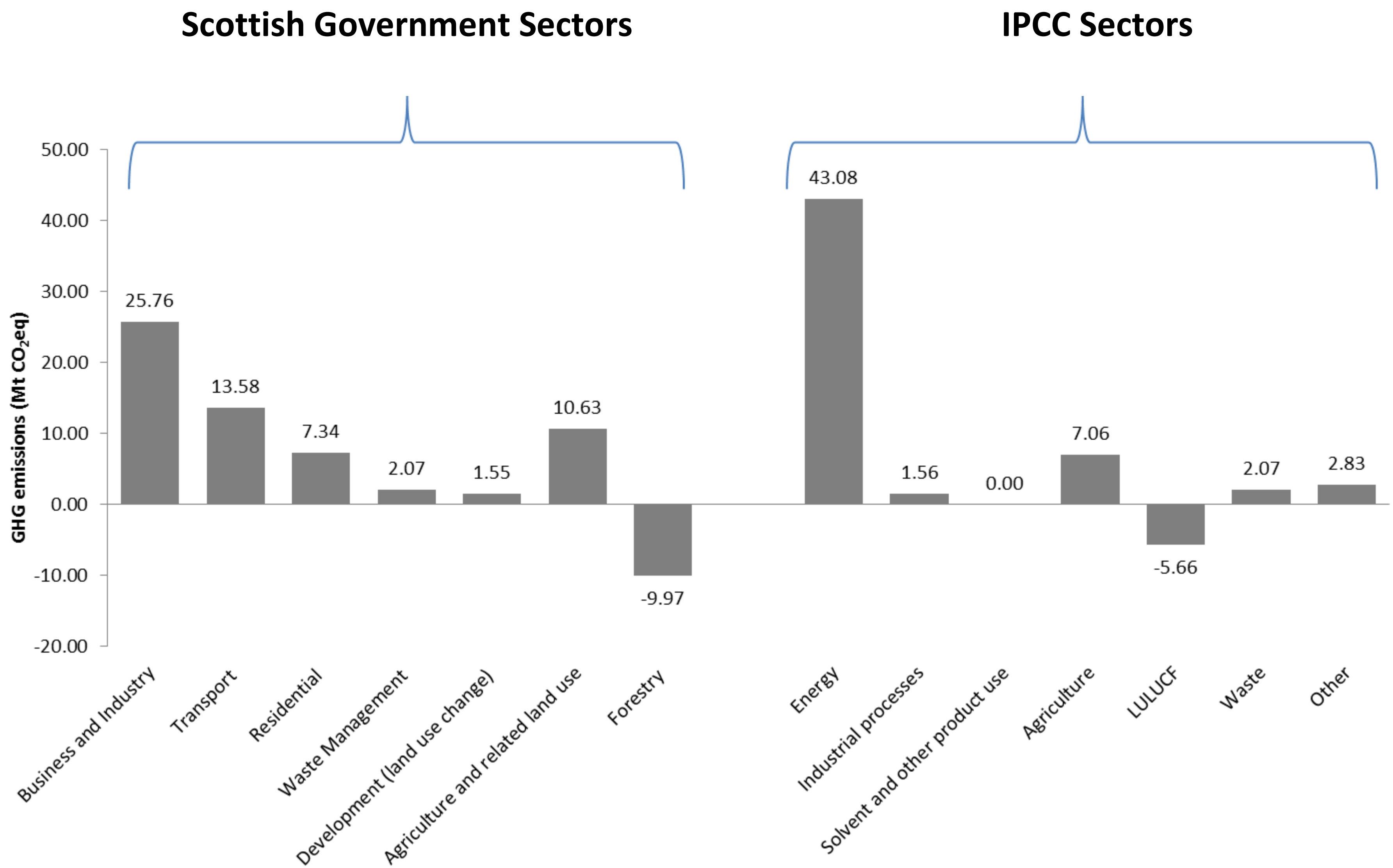
Scottish Government Sectors
IPCC Sectors
GHG emissions (Mt CO_2eq)
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
25.76
13.58
7.34
2.07
1.55
10.63
-9.97
43.08
1.56
0.00
7.06
-5.66
2.07
2.83
Business and Industry
Transport
Residential
Waste Management
Development (land use change)
Agriculture and related land use
Forestry
Energy
Industrial processes
Solvent and other product use
Agriculture
LULUCF
Waste
Other

Fig. 1.

Source of agricultural emission	Detailed source	NC	IPCC
1. Soils	Agricultural soils	✓	✓
	Field burning of agricultural residues	✓	✓
	Cropland (biomass burning - controlled)		
	Liming (cropland)		
	Cropland remaining cropland		
	Grassland (biomass burning - controlled)		
	Grassland remaining grassland		
	Liming (grassland)		
	Wetlands remaining wetlands		
	Non-CO_2 emissions from drainage of soils and wetlands		
2. Fuel and Agrochemical Use	Agriculture/Forestry/Fishing: Stationary	✓	
	Agriculture/Forestry/Fishing: Off-road	✓	
	Chemical Industry Other	✓	
3. Cropland conversion	Land converted to cropland		
	Land converted to grassland		
	N_2O emissions from disturbance associated with land-use conversion to cropland		
4. Livestock: manure storage	Manure management: Deer	✓	✓
	Liquid systems	✓	✓
	Solid storage and drylot	✓	✓
	Other	✓	✓
	Manure management: Dairy	✓	✓
	Manure management: Non-Dairy	✓	✓
	Manure management: Sheep	✓	✓
	Manure management: Goats	✓	✓
	Manure management: Horses	✓	✓
	Manure management: Swine	✓	✓
	Manure management: Poultry	✓	✓
5. Livestock: enteric fermentation	Enteric fermentation: Deer	✓	✓
	Enteric fermentation: Dairy	✓	✓
	Enteric fermentation: Non-Dairy	✓	✓
	Enteric fermentation: Sheep	✓	✓
	Enteric fermentation: Goats	✓	✓
	Enteric fermentation: Horses	✓	✓
	Enteric fermentation :Swine	✓	✓

Table 1. Emissions/sequestration included in the Scottish Government *Agriculture and Related Land-use* inventory. The IPCC and National communications (NC) columns indicate whether these emissions are included in these *agricultural* inventory/emissions accounting guidelines

	IPCC guidelines sector						
Scottish Government sector	Energy	Industrial Processes	Solvent and other product use	Agriculture	LULUCF	Waste	Other
Business and Industry	✓	✓	✓				
Transport	✓						✓
Residential	✓	✓					
Waste Management						✓	
Development (land use change)					✓		
Agriculture and related land use	✓	✓		✓	✓		
Forestry					✓		

Table 2. Scottish Government GHG emission inventory sectors, and their relationship to sectors used in IPCC guidelines. A 'tick' indicates the IPCC sector emissions that are included in the respective Scottish Government sectors.

Emissions source	IPCC guidelines sector
Cropland biomass burning	LULUCF
Liming (cropland)	LULUCF
Cropland remaining cropland	LULUCF
Grassland biomass burning	LULUCF
Liming (grassland)	LULUCF
Grassland remaining grassland	LULUCF
Wetlands remaining wetlands	LULUCF
Non-CO_2 emissions from drainage of wetlands	LULUCF
Land converted to cropland	LULUCF
Land converted to grassland	LULUCF
N_2O emissions from disturbance associated with land-use conversion to cropland	LULUCF
Agriculture stationary combustion	Energy
Miscellaneous industrial/commercial combustion	Energy
Agricultural engines	Energy
Agriculture: mobile machinery	Energy
Agriculture: agrochemicals use	Industrial processes
Agricultural soils	Agriculture
Field burning of agricultural residues	Agriculture
Livestock: enteric fermentation	Agriculture
Livestock: manure storage	Agriculture

Table 3. Sources of emissions included in the Scottish Government *Agriculture and Related Land-use* sector, and the IPCC sector to which they are attributed.

	NC emissions (Mt CO_2eq)		**SG emissions** (Mt CO_2eq)		**% reduction**	
	1990	**2010**	**1990**	**2010**	**NC**	**SG**
Scotland	9.83	7.95	14.26	10.46	19.13	26.64
England	40.09	31.67	45.41	33.25	21.00	26.78
Wales	7.17	5.67	7.88	6.08	20.92	22.81
N. Ireland	5.85	5.26	6.13	5.23	10.09	14.73
UK	62.94	50.55	73.68	55.02	19.69	25.3
EU15	434.00	374.00	566.75	484.89	13.82	14.44
EU27	594.00	462.00	758.43	596.96	22.22	21.29

Table 4. The difference in size of agricultural GHG emissions and emission reductions calculated for the UK and EU-15 and EU-27 countries depending on the inventory method used. NC relates to emissions from agricultural sources included in National Communications, and SG to those included in the Scottish Government approach.