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Towards a framework for a GHG emissions reduction strategy for rural land use and the land based industries in South West England

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CRPR Research Report No 25

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A Report for the Regional Environment Network

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CRPR Research Report No. 25
ISBN 978-1905892068
£15

The views expressed in this report are those of the author and are not necessarily shared by other members of the University, the University as a whole or by the Regional Environment Network.

Acknowledgements

A large number of people have provided information and shared their thoughts with me during the preparation of this report. In no particular order, I am grateful to Richard Bradbury, Adrian Colston, John Varley, John Wilding, Mark Broadmeadow, Mark Durk, Laura Cardenas, Agustin del Prado, Les Firbank, Oliver Harwood, Allan Buckwell, David Smith and Mark Robins. Apologies to anyone I have missed. All errors are mine.

Contents

Glossary

AD:	anaerobic digestion
CH_4:	methane
CO_2:	carbon dioxide
CO_2e	carbon dioxide equivalent
GHG:	greenhouse gas
N:	nitrogen
N_2O:	nitrous oxide
NH_3:	ammonia
NH_4:	ammonium
NO_3:	nitrate
t:	tonne

Towards a framework for a GHG emissions reduction strategy for rural land use and the land based industries in South West England

1. Introduction

This project has begun the development of a framework to identify the most significant opportunities for GHG (Greenhouse gas) emission reductions in rural land use and in the land based industries (food, and woodland and forest products) of South West England. The "Towards" part of the title of this project is quite important as, realistically, given financial and time constraints, this is only an initial attempt to guide thinking on a particularly complex issue. Furthermore, it has been necessary to focus more on primary land use practices and less on other elements of the food and forest product chain. Research conducted by the Food Climate Research Network looking at emissions from the horticulture, meat and dairy sectors also focused largely on primary land use and management issues arguing that "…it is generally agreed that post-farm gate emissions are far less significant…" and that "Post farm gate emissions may be easier to tackle since there is only one gas of any significance to address – carbon dioxide" (Garnett 2007, p.13). In addition to identifying opportunities for GHG reduction, the project has attempted to place these (1) in order of effectiveness in GHG reduction and (2) in terms of ease of achievement.

The framework has been developed from a review of key documents, discussions with experts, both within the region and beyond, and a consideration of a number of initiatives underway in the region. Where possible, ordering the individual GHG reduction actions in terms of the magnitude of potential contribution and ease of implementation has been done through canvassing expert opinion and reference to the relevant literature. This needs to be repeated on a wider scale within the region in order to improve reliability and stakeholder buy-in. The remainder of this report is structured as follows: Section 2 briefly reviews the contribution of the land based sector to GHGs. Section 3 identifies the main mechanisms, practices and actions that can be used for GHG mitigation in the rural land based sector. Section 4 presents a brief review of the current state of knowledge regarding GHG mitigation and considers some initiatives from the region that may offer wider lessons. Section 5 presents the rationale for the framework and the framework itself, while Section 6 highlights some of the transition issues that need to be addressed and identifies some key next steps.

2. Contribution of the land based sector to GHGs

Agriculture and forestry contribute some 7% of the UK's total GHG emissions. CO_2 emissions are a relatively minor component of this and are offset by the carbon extraction and storage activities of agriculture and forestry (see below). On the other hand, agriculture is a substantial source of methane (CH_4) and nitrous oxide (N_2O). Both of these gases are long lasting and have a more potent GHG effect per molecule than CO_2 (21 and 310 times CO_2, respectively). Agriculture is a source of approximately 40% the UK's CH_4 emissions, the majority of which derive from enteric fermentation by livestock, although liquid and solid manures are also a source of CH_4. Nitrous oxide is a by-product of soil processes. Management practices which result in excess nitrate in the soil (from fertilisers, manures and natural soil processes) create a potential for N_2O emissions, particularly when soils are wet. Agriculture is responsible for 65% of the UK's N_2O emissions.

Forestry and agriculture are arguably in a unique position with regards to carbon emissions. Other than energy use, carbon emissions largely result from actions such as ploughing, soil disturbance, harvesting wood and peat extraction. Retaining and enhancing existing carbon sinks, creating carbon sinks and adopting land management actions to reduce carbon emissions have the potential to make important contributions to carbon storage and reduced carbon emissions. In this context peat is particularly important. Quite simply, peatlands trump all other carbon stores, including forestry: The entire UK forestry estate stores an amount of carbon roughly similar to the UK's annual CO_2 emissions. Most peat in the UK is found in Scotland. Peat soils in England and Wales store the equivalent of 3 years UK emissions (Thompson, 2008). More locally, the carbon pool (which is largely peat based) on Dartmoor alone has been estimated to be 7.5 times the annual CO_2 emissions for Devon (Colston, no date).

3. Mechanisms, practices and actions

There are three mechanisms for GHG mitigation in the land based sector:

- **Reducing direct emissions** (e.g. reducing N_2O emissions from land and CH_4 from livestock)
- **Enhancing removals** (e.g. sequestering (withdrawing) CO2 from the atmosphere and building soil C sinks)
- **Avoiding/displacing emissions** (e.g. reducing fossil fuel use and/or displacing fossil fuels with renewables)

Although the brief for this project refers to a "GHG emissions reduction strategy" this was taken to encompass the three GHG mitigation mechanisms. GHG mitigation mechanisms can be categorised according to the broad type of management practice involved e.g.

- Land management (arable and grazing lands & forestry)
- Livestock management
- Manure management
- Land use change
- Bioenergy

While this provides a useful means of distinguishing between the different management arenas in which action can take place, it should be noted that these categories are not necessarily completely independent and consequently it can be difficult to assign a particular action to a single management category (Moorby et al 2007). Finally, it is possible to identify a range of specific actions such as reducing livestock numbers, reducing fertiliser usage, minimal tillage, improved woodland management, biomass production for fuel. It is actions such as these that are the subject of the framework described below.

4. What we know about reducing GHG emissions

Many practices can potentially mitigate GHG emissions. The most significant include improved land management, restoration or degraded soils, land use change, livestock management and manure management. This section briefly reviews existing knowledge and some interesting regional initiatives in order to inform the framework presented in the next section.

Smith and colleagues (2008, 2007) have produced extensive reviews of GHG mitigation options in agriculture and have considered the policy and technological constraints to the implementation of such options. According to Smith et al 2008, globally, the most important agricultural practices that can potentially mitigate GHG emissions are improved management of arable and grazing lands and the restoration of degraded land and organic soils. Actions with a lower priority, but which nevertheless offer significant potential, include water management, set aside, land use change, agroforestry, livestock management and manure management. The authors argue that, despite the biophysical potential for GHG mitigation in agriculture, little progress has been made since 1990 due to a range of barriers including the implementation of appropriate policy, institutional, social, educational and economic constraints. In this context communication and capacity building within the community of land managers is seen as important so that land managers become increasingly well informed regarding climate change and aware of the potential opportunities and benefits that are associated with mitigation actions. Significantly, they also argue that because of the uncertainties surrounding the science of GHG mitigation that it is important that mitigation options are also shown to deliver other environmental benefits as well as contributing to social and economic sustainability. In an earlier paper considering carbon sequestration and biomass energy offset, Cannell (2003) also argued that "although the theoretical potential offsets are high, when critical consideration is given to the constraints, especially land use, the realistic and likely achievable offsets are more modest" (p.111).

Bearing in mind the difficulties associated with estimating potential impacts of mitigation actions, a report jointly produced by IGER and ADAS (Moorby et al 2007) reviews research to identify best practices for reducing GHG emissions from agriculture and rural land management. It identifies a range of options and estimates the magnitude of emissions in terms of CO_2e and the direction and magnitude of mitigation impact (where known) on CO_2, N_2O and CH_4. Interestingly, it also categorises mitigation actions into three groups:

- those considered to be practical now, including not exceeding crop N requirements, AD and biomass production.

- future potential mitigation methods (those requiring further research and/or regulatory change), such as nitrification inhibitors.

- speculative mitigation measures (those that are still at the speculative stage but where existing evidence points to some potential) such as genetic manipulation of livestock.

In time, the approach adopted in this research will allow estimates of emissions and mitigation potential to be derived at the regional and sub regional level.

One of the actions that has been advocated for reducing carbon losses from soil and improving soil carbon storage is reduced-, minimum-, or no-till agriculture. The basic premise is that since soil disturbance stimulates carbon loss, reducing soil disturbance will help enhance carbon retention (Smith et al 2008). This is a complex area with a range of secondary impacts on N_2O and NO_3. Moorby et al (2007) argue that whilst reduced tillage options have future mitigation potential more work needs to be carried out on the overall GHG balance associated with such practices. Baker et al (2007) are more critical, arguing that "the widespread belief that conservation tillage also favours carbon sequestration may simply be an artefact of sampling methodology" (p.4). This is based on an argument that shallow soil sampling has biased the results of previous research. However, the same authors point out that there are many good reasons for promoting reduced tillage, including reduced production costs and reduced consumption of fossil fuel. Similarly, an ADAS report on reduced tillage (Bhogal et al) adopts and extends the Baker critique of reduced tillage pointing to widely differing impacts according to the depth of soil sampled, but also pointing out that much of the soil carbon stores developed as a result of reduced tillage will be lost when the land is eventually ploughed (probably every 3-4 years). Nevertheless, they also identify a range of other impacts such as reduced erosion and increased soil water retention.

Another controversial area is that of bioenergy. Bioenergy is the collective term for *liquid biofuels* produced from organic matter, *biomass*, which is solid organic matter (from sources including woody perennial crops such as miscanthus and short rotation coppice), and other non-fossil organic fuels such as biogas (produced through anaerobic digestion of agricultural residues and food waste). The controversy associated with bioenergy largely, but not exclusively, derives from concerns over the environmental impacts of first generation liquid biofuels. A recent report by the House of Commons Environmental Audit Committee (2008) was highly critical of the government's promotion of first generation liquid biofuels and the associated relative neglect of biomass. In addition, in a wide ranging review of the research literature on bioenergy from agriculture and forestry, Cooper and Arblaster (2007) argue that:

> "in spite of the rhetoric, the use of first generation biofuels is not a panacea for the reduction of GHG emissions. This is both because the input of fossil fuel energy during crop production and the conversion process is often high, and because the production of biofuel feedstocks results in the depletion of the terrestrial carbon sink and the release of N_2O from fertilised soils" (p.20).

It is likely that future, second generation, liquid biofuels will be much more efficient and deliver greater GHG savings (The Royal Society, 2008; Cooper and Arblaster, 2007). However, given concerns over the production of most current liquid biofuels and the Environmental Audit Committee's recommendation for "a moratorium on polices aimed at increasing the use of biofuels" (p.32), the remainder of this section is confined to biomass and biogas.

The use of woody biomass for combined heat and power generation offers high efficiency and GHG savings (Cooper and Arblaster 2007). Biomass sources include woody perennial crops, forestry and straw residues and thinnings. In addition to displacing fossil fuel use, additional benefits derive from biomass as the land is not cultivated annually and nitrogen fertiliser requirements are low. There is also the potential for biodiversity benefits, although this requires further research (Moorby et al, 2007). There is great potential for biomass supply from both existing woodlands and new plantings. It is estimated that, nationally, some 4 million tonnes (Mt) of biomass material is potentially available from England's under-managed woodlands, of which 50% is thought to be accessible (Forestry Commission, 2007). Under the England Woodfuel Strategy, the target for biomass supply is an additional 2 Mt of biomass brought to market annually by 2020. Further sources of supply come from arboricultural arisings (residual wood from felling, pruning, etc) as well as recovered wood from businesses and households. It is estimated that, from the latter source alone, 6 Mt is currently disposed of to landfill annually (Forestry Commission, 2007).

The other form of bioenergy considered for this report is biogas production through anaerobic digestion (AD). AD uses manures to generate methane for energy production (vehicle fuel, heating, electricity generation) and a digestate that can be used as a fertiliser and soil conditioner. AD can significantly reduce methane emissions from slurry storage (Moorby et al 2007). It is possible to distinguish between farm scale AD operations and large scale Centralised Anaerobic Digestion (CAD) plants. The latter can improve CH_4 yield through the addition of food wastes for which they can also charge a gate fee. According to Cooper and Arblaster (2007), biogas production at the farm scale has "a favourable GHG emissions footprint compared to fossil fuel" (p. 23). However, they and others note that biogas production is often enhanced by the addition of maize which raises biodiversity concerns.

Poor economic returns and a lack of incentives have been blamed for the slow development of AD in the UK. Start up costs are high and economic returns can be low, or even absent (Butler, 2008). Opportunities for enhancing returns derive from gate fee income, selling electricity to the national grid and selling digestate. Enviros (2007) have identified a range of barriers to the expansion of AD including financial barriers, policy barriers, environmental barriers, technical barriers, infrastructure barriers and a lack of awareness. Nevertheless, they identified a "significant *technical* potential for an increase in uptake" (p.ii, emphasis added). In this context, it has been argued that, although much can be achieved by improving the markets for the products of AD and by improving land manager knowledge and confidence, social acceptability remains a significant barrier (Butler, 2008). There are also a number of outstanding research issues such as the effects of animal feed on the quality of manures used for AD, the implications of applying digestate to land as a substitute for manure (Moorby et al, 2007).

The role of forestry has been briefly mentioned above. In addition to the potential for brining un- and under-managed woodland back into management for woodfuel, other management changes such as 'continuous cover' forestry can enhance carbon sequestration and storage (Thompson 2008). New planting can also play a role as part of a package of forestry related measures. Perhaps the most important point is that woodlands need to be actively managed as this can increase their resilience to climate change at the same time as contributing to mitigation efforts (Broadmeadow, personal communication). Increasing the use of timber in the construction industry could also deliver significant GHG savings. This is an area beyond the scope of this report but see ECCM 2006 for further information).

Within the South West there are a number of initiatives and market experiments from which lessons can be learned as part of the development and implementation of a regional strategy. This project did not, and could not, attempt a comprehensive survey (although that would be a worthwhile exercise) but the following examples are presented in order to illustrate some of the actions undertaken in the region to address GHG emissions and which, importantly, illustrate some of the multiple environmental benefits of such actions.

The importance of peat has already been stressed in this report and there are initiatives underway in the region to help understand how well our peatlands are performing and to restore degraded peat. For instance, the Exmoor Mire restoration project aims to enhance carbon sequestration and storage as well as reducing erosion and flood risk, improving aquatic ecology and delivering biodiversity objectives. Although covering a relatively small area of Exmoor's degraded peatland, the mire project demonstrates the multiple benefits associated with peat restoration. For further details visit the project website[1]. There is also activity on Dartmoor to establish the extent of the soil carbon resource, how it is currently performing and how it can be improved. The National Trust, Duchy of Cornwall, Natural England and Dartmoor National Park Authority are co-funding a Great Western Research PhD student at Plymouth University who is studying Policy and Practice for the Sustainable Carbon Management of Moorlands. This work is at a very early stage but should ultimately provide a valuable input into the debate about carbon and peat management. The National Trust's involvement in this area is particularly interesting in that they are exploring the feasibility of adopting a '20% net gain' policy for carbon (i.e. for every 80kg of carbon emitted 100kg of carbon would have to be 'banked' on NT property). This new approach to 'carbon stewardship' would see the Trust:

1. Enhancing the performance of all their current carbon sinks
2. Creating new carbon sinks
3. Stabilising all current carbon stores (the 'bank') and sustaining them in favourable condition
4. Creating new carbon stores
5. Reducing the output of carbon - from land, and from all fossil fuel associated emissions.

Within Devon and Cornwall activities to achieve these aims could include the use of hydro-electricity and biofuels as well as action to restore peat and a wide range of other initiatives[2].

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[1] http://www.exmoor-nationalpark.gov.uk/index/looking_after/looking_after_landscape/moorlands/moorlandinitiative/mire.htm

[2] For further information contact Adrian Colston, the NT's Dartmoor Property manager: Adrian.Colston@nationaltrust.org.uk

Further research on land and carbon is being undertaken by the West Country Rivers Trust as part of its Landscape Carbon Sequestration Project. The project aims to:

1. Establish a database of rural land forms and their carbon content

2. Establish a catchment map of 'land in need of restoration'

3. Use 1 and 2 to calculate the potential net increase in carbon content in catchments where all 'land in need of restoration' has all been restored.

This project is still in progress[3] and may be developed further under a proposal for an Interreg project addressing climate change on a local and interregional scale. The proposal is being developed by Andy Bell, Chairman of the UK Man and Biosphere Programme.

In the private sector there are also some interesting examples of initiatives to reduce GHG emissions and displace the use of fossil fuels. For example, as a large, benevolent landowner, Clinton Devon Estates (CDE) is leading the way in demonstrating the market potential and business benefits associated with renewable energy. CDE is experimenting with, and exploring, a number of options including the feasibility of developing a large AD plant on a brownfield site. They are also using biomass energy in the estate office and are looking at scenarios to extend the technology to heat a range of estate properties. Although not explicitly designed as a demonstration activity, the CDE initiatives nevertheless can help inform other, smaller scale, actions in the region. In particular, the Estate's experience with Biomass heat generation can help inform farmers on how to become 'heat entrepreneurs', supplying biomass to local communities and making new economic and social connections in the process.

5.1 Towards a framework for a GHG emissions reduction strategy

There are potentially many elements that *could* be included in a framework to guide the development of a GHG reduction strategy. In one sense, the greater the complexity of the framework the harder it is for it to provide a clear steer. On the other hand, an overly simplistic framework would risk omitting important issues. Bearing this in mind, the framework developed so far contains 6 main elements (as described below). A 7th element concerning the cost of implementation and economic impact at the business level should be included in any framework to guide strategy development but is beyond the scope of this project. In this context it should be noted that there are research projects in the region already underway, or soon to begin, that will provide cost estimates and data on economic implications for certain actions (e.g. AD). An additional element that *could* be added to the framework is some indication of the social acceptability of specific actions. This could be done on the basis of

[3] Contact Dylan Bright at WRT for further information: dylan@wrt.org.uk

stakeholder deliberation and/or empirical investigation. It could form an element of the framework as it would give an indication of the likely wider public support which specific actions could benefit from.

In considering the actions listed in the framework it should be noted that the SW region is not a closed system, and that actions taken within the region may simply move problems elsewhere.

5.2 Framework rationale

i) Action: brief description of the action to be taken to reduce GHGs

ii) Potential contribution: assessment of the farming system and land use to which the specific action is most applicable and its potential to reduce GHGs. This element involves a consideration of several aspects which could be examined separately but which in combination provide an indication of overall *potential* contribution. An estimate of the size of the farming system and land use to which an action is applicable are clearly useful indicators (see Tables 1 and 2), although it should be noted that in the absence of detailed, farm level data, it can only be a rough guide. In addition, as Cannell (2003) has argued, there is an important distinction to be made between theoretical, potential and achievable capacities to reduce GHGs. The *theoretical* potential ignores all practical constraints (e.g. assuming all land can be afforested to maximise carbon sequestration). *Realistic capacity* denotes an optimistic scenario regarding constraints, opportunities and social acceptability. Finally, *conservative, achievable* capacity presents a cautious assessment based on existing trends and with few optimistic assumptions. Similarly, Smith et al (2005) distinguish between the maximum biophysical potential, the economically constrained potential and the socially/politically constrained potential of mitigation actions.

At present it is not possible to quantify the impact on GHG reductions at the regional level although in the coming months research being conducted by IGER will allow the quantification of emissions and modelling of emission reduction impacts at the county scale. Modelling work by the Environment Agency will also allow an exploration of interactions resulting from actions to reduce GHGs.

Table 1. Number of agricultural holdings by type in SW GOR, 2006

Holding type	Number	% of farms in SW region
Cereals & General cropping	3,604	13%
Horticulture	2,413	8%
Pigs & Poultry	1,906	7%
Dairy	4,509	16%
LFA livestock	2,414	8%
Lowland livestock	10,744	38%
Mixed	2,935	10%
Total	**28,525**	**100%**

Source: Defra June Agricultural Survey

Table 2. Land use on agricultural holdings in the SW GOR, 2006

Land use type	Ha	% of farmed area
Crops & bare fallow	480,683	26%
Temporary grass	194,063	10%
Permanent grass	954,914	50%
Rough grazing	90,826	5%
Woodland	69,882	4%
Set aside	57,764	3%
Other land	29,735	2%
Total	**1,877,867 ha**	**100%**

Source: Defra June Agricultural Survey

Table 3 Woodland cover in the South West

Woodland size (ha)		Total area	% of region under woodland
0.1<2.0 ha	=>2 ha		
6,412	205,611	212,023	8.9

Source: National Inventory of Woodland and Trees, 2001

iii) Potential environmental side affects: impacts on other GHGs and other valuable ecosystem services. Whilst a specific action may be targeted towards a reduction in a particular GHG, many actions can have +/- impacts on other GHGs as well as wider implications. As Smith et al (2007) argue such "co-benefits and trade-offs" may vary over space due to different underlying conditions and due to the way a specific action is implemented. They go on to argue that given the "complex, interactive effects on the environment" stemming from individual GHG reduction actions that "the merits of a given practice … cannot be judged solely on effectiveness of mitigation" (p.9).

iv) Ease of implementation: how easy an action is to adopt by land managers. All other things being equal, the easier it is to adopt a new practice, and/or to modify existing behaviour, the more likely that the change in behaviour will occur. However, barriers to implementation exist in the form of transaction costs, uncertainty, knowledge and skills gaps, availability of support (in terms of capital support and KT).

v) Support needs: need for KT/KE, grant aid, etc. Specific needs follow on from the assessment of the ease of implantation.

vi) Knowledge needs: main knowledge gaps associated with each action. While there are many "known knowns" in the field of GHG science there are also many unknowns and debate and uncertainly about some 'apparent knowns' for instance, the ability of minimum/conservation tillage to promote carbon sequestration (see Baker et al 2007). There are also specific knowledge gaps and information needs regarding key environmental data in the region which makes assessing the magnitude of potential impact a challenging exercise.

vii) Cost and economic impact: this has not been included in the framework presented below but it should nevertheless be a key consideration. It is important to understand the direct cost to the land manager associated with implementing a specific action, the wider economic implications for that business and connected businesses and the cost of any direct support needs. Ultimately, consideration should be given to valuing the overall benefit deriving from a given action on a range of ecosystem services and not just the carbon-equivalent costs and benefits.

viii) Social acceptability: again, this has not been included in the framework presented here but it is an important consideration. Regardless of the environmental imperative, mitigation actions which have the backing of the wider community are likely to be more widely adopted.

5.3 Suggested 'top 8' regional GHG reduction actions

In addition to specific actions to mitigate GHGs, widespread adoption of carbon accounting, while no panacea and subject to various caveats, would at least encourage owners/operators of rural land based businesses to consider the impact of their actions and ways in which they could change their behaviour.

- **Actions to manage inputs and outputs of Nitrogen,** but in particular matching Nitrogen to crop requirements. Potentially applicable to most farm holdings in region.
- **Maintaining and enhancing peat** – our most *valuable and vulnerable* carbon store. Data on extent of peat soils in region is not easily available but their potential is disproportionate to their extent.
- **Maintain & expand permanent grass** – avoiding soil carbon losses
- **Minimum tillage of arable soils** – reducing soil carbon losses and saving emissions through reduce fuel use.
- **Improved woodland management** – much of region's woodland currently un/under-managed (an estimated area of 105,673 ha)[4]. Would improve carbon sequestration & storage & provide substitutes for fossil fuel.
- **New woodland planting** – improves carbon storage and sequestration, potential source of biomass for fuel, timber for construction and can provide landscape, biodiversity and recreational benefits.
- **Biomass management** for bioenergy – SRC & miscanthus[5] – **not** arable energy crops
- **Anaerobic Digestion** – very significant methane reduction (up to 90%) & beneficial carbon impacts though fossil fuel displacement.

[4] Durk, personal communication.

[5] There is also a possibility that Low-Input High-Diversity (LIHD) Grassland could make a significant contribution to producing energy and reducing GHG emissions. This is an area subject to some controversy in the USA (see for instance Tilman et al 2006 and 2007) but does not appear to have been considered in the UK so far.

5.4 Draft framework for a GHG emissions reduction strategy

Action	Potential contribution	Potential environmental side effects	Ease of implementation	Support needs	Knowledge needs
Carbon accounting	Potentially important indirect contribution in terms of awareness raising.		CLA launched free, on-line carbon accounting system: www.cla.org.uk/Policy_Work/CALM_Calculator/	Guidance and advice	Wise to develop alternative tools to enable assessment of uncertainty
Nutrient management: matching N to crop requirements	Poss. 5% reduction in N_2O.[6] Potentially applicable to approx 26k farm holdings. Less likely to be applicable to LFA farms and other extensive systems	Reduction in NO_3 leaching and NH_3 emissions. Good for water quality & aquatic biodiversity. No negative impacts.	Appropriate fertiliser recommendation systems exist.	KT – education and guidance in use of recommendation systems and in enacting recommendations	Research impacts on wider range of crop types. How to best bring about change in farmer behaviour
Nutrient management: making full use of manure N supply	Potentially applicable to all farms but most suitable for intensive grass and arable farms receiving manure. Would reduce mineral N fertiliser use and N_2O emissions of poss. 5%[7]	Reduced NO_3 leaching. Good for water quality & aquatic biodiversity	Appropriate fertiliser recommendation systems exist.	KT, Advice, education and on-farm analysis and guidance.	How to best bring about change in farmer behaviour

[6] Moorby et al 2007
[7] Moorby et al 2007
[8] Moorby et al 2007

Action	Potential contribution	Potential environmental side effects	Ease of implementation	Support needs	Knowledge needs
Nutrient management: improved timing of slurry and manure applications. No applications in autumn/early winter or to bare ground	For farms using slurry & poultry manure. Sig reduction in N_2O emissions – poss. up to 10%[8]	Reduction in NO_3 leaching but increases in NH_3.small increase in CH_4. Good for water quality & aquatic biodiversity	Need sufficient storage to give choice of when to spread slurry	KT, slurry storage facilities.	Further research to quantify impacts on different soil types
Nutrient management: Use of legumes in rotations	Significant potential increase in soil carbon if adopted at large scale. Reduced N_2O through reduced fertilizer applications	Soil C saving potentially lost through subsequent tillage actions	May be farmers concern re. bloat	Demonstration and advice needs.	
Maintain/enhance/restore carbon sinks: peatlands	Unlike other soils, blanket bog acts as perpetual carbon sink if un-degraded. Re-wetting, reducing stocking densities and frequency of burns, restoring vegetation could lead to C savings of 10-30 tC/ha/yr[9]	Short term increase in CH_4 emissions. +ve biodiversity gains and other environmental services, including water quality &, possible, flood risk mitigation (FRM)			Quantifying carbon loss associated with specific management & improved quantification of carbon savings associated with restoration. Examples in the region and from northern England will provide much needed knowledge.

[9] Thompson 2008

Action	Potential contribution	Potential environmental side effects	Ease of implementation	Support needs	Knowledge needs
Reduced/min tillage systems	Potentially applicable to all farms with crops (> 6k in SW). Would help maintain surface organic matter & preserve soil structure. Reduces NO_3 leaching. Most applicable to east of the region?	May increase N_2O. Increased soil carbon storage but this lost when land eventually ploughed. Reduced production costs and energy (fossil) fuel savings Can help biodiversity, water quality, soil retention	Already used on some 1.5 m ha nationally. Not suitable for light soils.	KT, demonstration events.	Implications of periodic ploughing for soil C content. Current scientific debate re. impact of sampling strategy on validity of research results. Need to establish overall impact on GHG balance
Land use change: permanent grassland and/or woodland	Increase soil carbon by conversion to **permanent** cropping e.g. arable to woodland or arable to permanent grass. Impacts in range of 1.9-7 t CO_2e/ha/yr depending on environmental conditions and management practices. Such increases not in perpetuity. New soil carbon equilibrium reached after 50 yrs +. In case of conversion to woodland carbon stored in the vegetation will increase +ve impact. Use of land for forestry estimated to sequester 2-9 times more carbon than the same land under biofuel production	Reduction in N_2O and NO_3. NO_3 benefits greatest on sandy/shallow soils that are most prone to leaching. Wider landscape and biodiversity benefits Soil protection, FRM, water quality Potential to displace food production pressures to other sensitive habitats/locations throughout the globe.	Seen as an extreme land use change. **Change must be permanent** for full benefits to be realised. Financial incentives likely to be needed but issues re. competition for land for food v non-food uses? (in case of woodland)	Financial incentives for woodland creation	

Action	Potential contribution	Potential environmental side effects	Ease of implementation	Support needs	Knowledge needs
Land use change: Bioenergy[10]	Displaces fossil fuel use & increases soil carbon storage. Potentially applicable to all land that can be cultivated. Where land use change is to **permanent** biomass cropping increased soil carbon storage of some 2.4 t CO_2e/ha/year	Reduces soil disturbance associated with annual cultivations, saves N due to modest fertiliser inputs. Reduced N_2O and NO_3		Probably requires financial incentives	Further work needed on impacts on biodiversity
Anaerobic digestion (AD)	AD of farm manures to generate CH_4 for heat. Poss. 90% reduction in CH_4 compared to conventional slurry storage[11]. Potentially applicable to all farms with livestock (some 20k in SW) but realistically likely to be much less than this. Farm animal waste can be supplemented by other wastes, including food waste.	Significant CO_2 savings through fossil fuel displacement. May be associated with environmentally undesirable land use change at farm level e.g. more maize.	High start up costs. Relatively new initiative for UK farmers. Quite a lot of research activity on AD currently underway which should clarify some of the barriers and support needs. Public concern and misunderstanding can be barrier	High start up costs & several year repayment period – need capital assistance? KT needs – advice & guidance Larger scale projects need assistance to develop appropriate networks of supply and support.	Long term implications for soil structure of applying digestate rather than unprocessed manure unknown.

[10] There are two main forms of bioenergy: perennial crops for heat and power such as *Miscanthus* and short-rotation coppice, and feedstocks for liquid biofuel (e.g. OSR for biodiesel). This is a lively and contentious area of debate, although there is a growing consensus that 1st generation feedstock for liquid biofuels are often not an effective means of GHG mitigation. Therefore this section relates to permanent biomass crops only.
[11] Moorby et al 2007

Action	Potential contribution	Potential environmental side effects	Ease of implementation	Support needs	Knowledge needs
Forestry: increased woodland establishment	Aggregate impacts of increasing new woodland establishment limited by area likely to be planted but on an area basis the total carbon gain can but quite significant. SWF estimate that the total carbon gain for new mixed woodland creation is 3.45 t C/ha/yr for 100 years	Range of other landscape, biodiversity and public well-being benefits from multifunctional woodland	Well established models of grant-aided new plantings.	Effective communications strategy re. multiple benefits of new planting backed by appropriate advice and grant aid.	
Forestry: woodfuel production	National target of additional 2mt by 2020 equates to saving of 0.4mt C/year. Oil fuelled boilers emit approx 0.265 kg CO_2/kwh compared to 0.025 for wood chip/pellet boilers.[12] Much of SW's 212000ha of woodland under/unmanaged but significant potential for woodfuel production. Could heat 50-60k homes[13] Mixed woodland for	Improvements to habitat quality. Well managed woodland makes larger contribution to mitigation than unmanaged woodlands. Biodiversity gains and improved resilience to effects of climate change	May be more difficult for owners of smaller woodlands. Therefore need to consider alterative arrangements for cooperative working, ensuring contract services available etc.	Ensure processing facilities available. Communication of the message re. role of woodfuels is a key need.	

[12] Ireland, Claridge & Pow (2006) Woodfuel meets the challenge, Forest Research.
[13] SW Regional Woodfuel Framework 2005.
[14] Broadmeadow 2006

Action	Potential contribution	Potential environmental side effects	Ease of implementation	Support needs	Knowledge needs
	bioenergy and product substitution can produce 4-5 times more carbon savings than unmanaged woodland.[14]				
The remaining actions are not in any particular order					
Increasing soil organic matter	Applications of FYM, crop/straw residues, sewage sludge, compost, paper can increase soil carbon & improve soil structure. 35% of UK Ag land currently receives organic returns (mostly grassland). Impact per ha relatively small so overall potential dependent on scale of uptake on region's arable land – some 480,683ha. Not as effective as land as change or AD and biomass burning	N_2O reductions (due to reduced fertiliser). Improved soil structure			Debate about impact in terms of increasing soil carbon. Partly depends on what would have happened to the organic material otherwise. Need for improved & comprehensive comparisons with other practices

[15] Estimate based on figures in Thompson 2008

Action	Potential contribution	Potential environmental side effects	Ease of implementation	Support needs	Knowledge needs
Land use change: field margins & hedgerows	6m margins for all tilled land in region could lead to additional 0.1 t C/year in the SW (combination of reducing emissions and increasing soil carbon).[15] Extending width of hedgerows 1m each side to create additional scrub/trees to store carbon.	Extending field margins will lead to reductions in NO_2. Depending on management regime other biodiversity benefits are likely. Also reduces run off to water courses.	Attractive to farmers as no need to take large areas of land out of production. 6m Field margin creation/management supported under ELS		
Land use change: habitat creation/restoration/maintenance	Change from intensive grass and/or arable can reduce GHG emissions & increase carbon storage. Wetland creation on arable land estimated to lead to additional 2.2-4.6 t CO_2e/ha/year[16]	Range of wider biodiversity benefits. Wetlands also for FRM and water quality improvement.	Principal well established under agri-environmental schemes although **change must be permanent.**	KT & guidance. Incentive payments	Need to quantify benefits in terms of GHG mitigation.
Improved feeding practices: avoiding excess N in diet	Up to 22.5k farm holdings but less applicable to outdoor pig and poultry units. Most impact on outdoor ruminants where grazed forage is greatest part of diet. Could yield 6% reduction in N_2O.[17]	Poss. CH_4 reductions. Reduction in NO_3 leaching	Requires updated nutrient standards for beef and sheep. Needs accurate analytical data re. chemical composition of forage feeds which may not be easily available. Increased	KT programme re. importance of improving livestock nutrient efficiency	Need updated nutrient standards

[16] Thompson 2008
[17] Moorby et al 2007

Action	**Potential contribution**	**Potential environmental side effects**	**Ease of implementation**	**Support needs**	**Knowledge needs**
			reliance on feed supplements could pose barrier		
Forestry: improved woodland management	Options such as continuous cover maintains canopy and minimises soil disruption at harvest to minimise soil carbon losses.	Creates uneven aged stands with biodiversity benefits & additional resilience to climate change	Need for market or other incentives		
Forestry: product substitution	Currently only produce 1/6 of timber used in UK so limit to extent to which domestic timber can substitute for other products. Nevertheless timber offers significant mitigation benefits over steel and concrete (for instance)				

6. Transitions and next steps

Pete Smith, lead author of the IPCC chapter on agriculture, has recently argued that, "GHG emissions from the agricultural sector are characterised by large uncertainties and it is difficult to assess the effectiveness of GHG mitigation measures" (Smith et al 2007 p.25). Smith and colleagues go on to argue that this makes consensus difficult to achieve and hinders policy making. They suggest, therefore, that identifying policies that provide multiple benefits (e.g. GHG mitigation and aspects of social, environmental and economic sustainability) is "critical for ensuring that effective GHG mitigation options are widely implemented in the future" (p.26). The difficulties and uncertainties Smith and his colleagues refer to are reflected in difficulties and uncertainties in ordinating the various mitigation options in terms of impact and ease of implementation.

There are many other issues to consider in the transition to policies and practices that mitigate GHG emissions from the rural land based sector. Some of these reflect scientific and technical uncertainties and others concern attitudes to risk in policy making and, more fundamentally, the property rights of individual business owners and entrepreneurs.

One of the transition issues we need to be aware of is the short term impact of land use change. For instance, where land use shifts from grassland to woody biomass production there is likely to be some short run loss of soil C. Similarly, there are complex GHG fluxes associated with re-wetting peat. Restoring degraded peat is one of the most significant actions that can be taken but there is evidence that in the short term there is an increase in CH4 emissions. In the medium term (20 years), evidence suggest that all emissions fall to below pre-restoration levels and the re-wetted peat acts as a net sink (EN carbon report). The policy community needs to be fully aware of these and other short term transition issues. The simple and rather crude message is that things might get worse before they get better but we can be confident that in the face of inaction, things will only get worse.

The complexity of GHG mitigation means that it is inevitable that there are various gaps in our knowledge. Some are simply due to lack of appropriate data at a regional or sub-regional scale, others are because complex interactions between GHGs have not been fully explored, or because there is only short term data or data for a specific type of soil, etc. The absence of complete knowledge, however, cannot become an excuse for inaction or simply the commissioning of further rounds of research (although it is obviously important!). There is a relatively narrow window of opportunity to take action now to mitigate against climate change impacts in the future. Consequently, it can be argued that there is a need to take some calculated risks regarding land management and land use.

One significant issue that will have to be considered (but is beyond the scope of this report) is the importance of permanence of land use change and implications for property rights. Land use change options have the potential to make significant contributions to mitigating GHG emissions but they must be permanent. This, in turn, suggests some curtailment on the 'freedom to farm' and property rights of other rural land holders. A system of covenants and compensation may provide the solution but it requires careful consideration.

On a more positive note, the land managing community of the SW region have displayed great willingness in the past to adapt their practices to meet the needs of environmentally sensitive farming and land use and it seems that given the appropriate policy framework, they will again embrace a new model of carbon sensitive farming and land management.

A number of further steps are required to develop the framework outlined here and to then use it to produce a regional strategy. Some of the most import actions are to:

- Establish regional intelligence database of initiatives and market experiments in region from which lessons can be learned for the development and implementation of regional strategy.
- Estimate magnitude of impact of priority mitigation actions identified in this report.
- Facilitate stakeholder deliberation regarding the efficacy of the top 8 GHG reduction measures and their social acceptability.
- Develop detailed guidance for land managers alongside a suitable support package.

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