CLIMATE CHANGE AND AGRICULTURE
Options for Mitigation of Greenhouse Gas Emissions from Agricultural Activity in Wales

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Executive Summary

1. Introduction

This report sets out the results of a Welsh Assembly Government (WAG) Technical Services Division (TSD) project to scope how Welsh Agriculture can:

- Reduce its greenhouse gas emissions on-farm from soils, crops and livestock, wastes and farm operations;
- Contribute to overall emissions reduction by on-farm use of bio-energy crops and other renewables.

The project has examined impacts for the Welsh agricultural sector and for the main types of farm units. It has not examined reduction of greenhouse gas emissions off-farm in the food chain.

2. Policy Context

Climate change policy has been addressed globally principally through the UN Framework Convention on Climate Change (1992). The aim is to stabilise greenhouse gas (GHG) concentrations in the atmosphere at a level which will prevent interference with the global climate system. Initial reduction targets have been set by the Kyoto Protocol, but reduction targets in the range of of 20-30% are required by the 2020s, and 60-80% by the 2050s to avoid global average temperature increases above 2^0C, where impacts are forecast to become very substantial.

The policy context for climate change in Wales is set by the Environment Strategy for Wales and the policy document 'One Wales', published in 2007. Welsh Assembly Government has set out its objectives to achieve annual reductions of carbon equivalent emissions by 3% per year from 2011 onwards, in areas of devolved competence from the UK government. The report 'Sustainable Farming and Environment – Action towards 2020' recommends that action is taken by the Welsh Assembly Government to achieve carbon neutral status for agriculture by 2020.

3. Historic Trends

The Greenhouse Gas Inventory for Wales (2005) estimates that the agriculture sector emits 1.64 Megatonnes (Mt) Carbon - 11% of the total Welsh emissions of 13.7 Mt Carbon[1]. The main agricultural and land use sources of greenhouse gases are:

[1] AEA Netcen Greenhouse Gas Inventories for England, Scotland, Wales & Northern Ireland 1990 – 2004 (2006)

- 0.13 Mt Carbon as carbon dioxide (CO_2), as direct emissions from on-farm combustion of fuels, microbial decay and release of soil organic matter in aerobic conditions. The use of electricity by agriculture, assigned by the inventory to the energy sector, gives additional emissions of 0.03 MtC.
- 0.74 Mt Carbon as methane (CH_4) (60% of total Welsh emissions of methane), from ruminants, stored manures and organic materials decomposing in anaerobic conditions in soils,
- 0.77 Mt Carbon as Nitrous Oxide (N_2O) (82% of total Welsh emissions of N_2O) from microbial reactions in soils and manures, predominantly a result of soil processes, including leaching of fertiliser nitrogen (27%), synthetic fertiliser application (19%), manure used as fertiliser (8%), ploughing in of crop residues (1%) and cultivation of legumes (< 0.1%)[2].

Nitrous oxide is approximately 250 to 310 times more effective as a greenhouse gas than CO_2 and methane around 21 times, making the reduction of these emissions a key issue for agriculture.

In addition to the above there is a contribution to emissions from cultivation and conversion between different land uses. This relates to the emissions and sinks from biomass and soils of different types - source 0.47 MtC; sink 0.59 MtC. (Net Sink of 0.12 MtC).

Also, the use of electricity by agriculture, estimated by the Carbon Trust as 0.256 Terewatt Hours, is equivalent to emissions of 0.03 MtC.

In total the sector emitted 2.14MtC and absorbed 0.59 MtC in 2005, a net emission of 1.55MtC.

These figures are for direct land use, and do not include any aspects of food processing and distribution and imported animal feedstuffs.

Comparison of emissions trends for Welsh agriculture shows there has already been a reduction of emissions by 10.1% for 2005 compared with 1990 – the usual baseline year for comparing emissions.

These changes reflect changes in the number of livestock and farm management – i.e. how the crop or animal is managed in terms of inputs and likely emissions potential.

4. Future trends – Business as Usual

[2] Scoping the environment and social footprint of horticultural food production in Wales, University of Wales Bangor, CALU 2007.

DEFRA has funded a study of baseline projections for UK agriculture[3]. Policy drivers that were considered included CAP reform, Rural Development Plan, Water Framework Directive, Nitrates Directive, Integrated Pollution Prevention and Control Directive, Waste Framework Directive, Climate Change agreements, and the REACH Directive. Projections to 2025 were based on a DEFRA Robust Farm Type model for future livestock and cropping patterns. The combined effects of structural changes and general improvement in management were forecast to lead to a reduction of UK emissions by 6% for methane and 3% for nitrous oxide. These are based mainly on a reduction in livestock numbers, for example through increasing annual milk yields per cow. For Wales, projected farm changes were reductions in livestock and increases in arable crops. On a pro rata basis from these UK estimates, this would lead to a further 4.1% emission reduction for Wales based on 2005 figures. It is important to take account of the historic trends and the projections in deciding on further interventions to reduce emissions.

5. Impact of Actions Identified to Mitigate Emissions on a Wales Basis

Agricultural mitigation options identified in this paper include:

- Methods to manage soil carbon retention and enhancement – eg through using ECOSSE guidelines in agri-environment schemes
- Ways to reduce nitrous oxide emissions – by more effective targeting of manure and fertilizer use
- Ways to reduce methane emissions – by anaerobic digestion and changing ruminant diets
- Growing and use of bio-energy in Wales – biomass and biofuels to substitute for fossil fuels
- Energy efficiency and microgeneration schemes for reducing emissions from agriculture.

In terms of potential emissions reduction based on the annual total of 6020Kt CO_2 equivalent[4], the main options are:

Soils and land use change

1. Avoid soil carbon loss from organic and organo-mineral soils by using ECOSSE[5] recommendations.
2. Expand wetlands and woodlands on mineral soils. Potential to reduce GHG emissions by expanding the carbon sink – eg 5% reduction from converting 400 hectares of grassland to woodland at a sequestration rate of 0.74t CO_2 e

[3] DEFRA Project SFF0601 Baseline projections for agriculture July 2007.

[4] AEA Netcen Greenhouse Gas Inventories for England, Scotland, Wales & Northern Ireland 1990 – 2004 (2006)

[5] Estimating Carbon in Organic Soils – Sequestration and Emissions (ECOSSE)

/year, or converting 840 hectares of grassland to wetland at a sequestration rate of 0.36t CO_2 e /year.

Manures and Fertilisers

1. Match nutrient requirements more closely to crop needs and apply at appropriate times – up to 1.4% emission reduction.
2. More efficient manure management in making full allowance for manure nitrogen supply, and spreading at appropriate times – up to 0.6% emission reduction.

Livestock Management

1. Increase milk yield per cow – up to 1.8% emissions reduction
2. Decrease cow replacement age and/or increase the longevity of dairy cows – up to 0.8% emissions reduction.
3. Increase technical efficiency in beef cattle production – up to 1.4% emission reduction.
4. Increase technical efficiency of lamb production – up to 1.6% emissions reduction.
5. Match feed rates to animal requirements – up to 1.4% emissions reduction for dairy, up to 1.5% reduction for beef and sheep.

Research on crop genetics, animal genetics and dietary additives to reduce emissions is on-going and short-term studies have shown encouraging results. But further research and testing is required to substantiate these findings. This is likely to take several years.

Arable and Horticulture

1. Use of green manures for arable cropping – up to 0.1% emissions reduction
2. Biomass heating for horticulture – up to 0.15% emissions reduction.

Bioenergy

1. Use of biomass crops to provide farm electricity – up to 1.6% emissions reduction.
2. Use of biodiesel or vegetable oil for on-farm fuel – up to 1.7% emissions reduction.

Anaerobic Digestion

1. Methane recovery from dairy farms – up to 1.8% emissions reduction.

In terms of cost effectiveness of measures for Wales, reducing some livestock stocking rates, afforestation, improving milk yields and large centralised anaerobic digestion plants are the most favourable. Recommendations for reducing emissions, and monitoring, data, and research are summarised below.

6. Recommendations

Mitigation

1. WAG to encourage land use change by afforestation or reversion to semi-natural / wet habitats of more unproductive species-poor marginal grassland to create farm sinks (although only the former is currently reflected in the Inventory), through current and future Axis II agri-environment initiatives.
2. WAG to continue to deliver nutrient and resource management planning and best practice advice through current regulation, agri-environment, Farming Connect and other KT programmes. Ensure that adherence to the Code for Good Agricultural Practice (COGAP) remains a prerequisite of Axis II agri-environment schemes.
3. WAG to deliver technical efficiency methods for the dairy, beef, sheep, arable and horticulture sectors through knowledge transfer mechanisms such as Farming Connect farm development programmes.
4. WAG to encourage farmers to take stock of farm emissions by use of an on-farm carbon-accounting tool such as the Carbon Accounting for Land Managers (CALM) calculator, in conjunction with best practice information through current and future knowledge transfer mechanisms as listed above.
5. WAG to consider support for on-farm CHP units linked with the delivery of land use change such as woodland planting and management.

Monitoring, Data and Research

1. WAG to liaise with DEFRA to support and review research on livestock management systems, including diets, livestock management, and nutrient/manure management (eg REDNEX project to reduce emissions in cattle) to the current variable data.
2. WAG to work with DEFRA to support and review research on soil carbon management and impacts of land use management, where current data are variable.
3. WAG to work with DEFRA on economic valuation of the costs and benefits of the reductions options is required particularly where options deliver a range of other benefits such as biodiversity and water quality.
4. WAG to work with DEFRA and other DAs to address knowledge gaps in the baseline data available. Many data are UK-wide or for England and Wales jointly. Examples are: the British Survey of Fertiliser Practice (BSFP), which could be extended to a larger sample of Welsh fields; whole farm fuel and electricity use; on-farm use of home grown energy crops; the current extent of the horticulture sector.
5. WAG to work with DEFRA to address knowledge gaps in the GHG Inventory and increase the sensitivity of the GHGI methodology to allow some of the mitigation options identified in this paper to be monitored in terms of tracking their contribution to Welsh GHG emissions targets.

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Bryn Thomas	Agri systems (beef & sheep), grassland
Ken Stebbings	Agri systems (dairy), ruminant emissions
James Skates	Soils, wetlands, zero tillage
Caryn Le Roux / Siwan Williams	Manures / fertilisers
Daniel Bevan	Cropping systems, pesticides, seeds, GMOs
Julie Bowes	Horticulture
Vicky Davies / Havard Prosser	Biomass, biofuels, anaerobic digestion, microgeneration

1 Introduction

Climate change policy has been addressed globally principally through the UN Framework Convention on Climate Change (1992). The aim is to stabilise greenhouse gas (GHG) concentrations in the atmosphere at a level which will prevent interference with the global climate system. There is general agreement that damage to the global economy and underpinning ecosystems will occur if ©á global warming exceeds 1-3^{o}C compared with pre-industrial temperature levels[6]. The Kyoto Protocol (1997) agreed a reduction of 5.2% of 1990 levels of GHG emissions for the industrialised countries for the period 2008-12. The EU is a signatory to the Kyoto Protocol and the UK has agreed to meet a 12.5% reduction target. The UK Government has also set an emissions reduction target for carbon dioxide of 20% by 2010, and 60% reduction target by 2050. Later this year, the UK Climate Change Committee will be assessing whether the target should be tightened to 80% reduction.

The policy context for climate change in Wales is set by the Environment Strategy for Wales and the policy document 'One Wales', published in 2007. Welsh Assembly Government has set out its objectives to achieve annual reductions of carbon equivalent emissions by 3% per year from 2011 onwards in areas of devolved competence from the UK government, and to set specific sectoral targets in relation to residential, public and transport sectors. Agriculture is an area of devolved competence, and it is important to identify how the sector can contribute to the overall objective of emissions reduction.

The report 'Sustainable Farming and Environment – Action Towards 2020' (2007) recommends that:

- Welsh Assembly Government should review existing research, available information and market opportunities to ensure Welsh farmers have access to the information necessary to help them adapt to climate change, reduce greenhouse gas emissions and take advantage of business opportunities.
- The Welsh agricultural industry should aspire to achieving overall carbon neutral status by 2020. An industry with a minimal carbon footprint will reduce its cost base, minimise the need for further regulation and acquire a significant marketing advantage.
- The Welsh Assembly Government should investigate the establishment of a more systematic approach to involving farmers in the provision of carbon off-setting and water management services.

[6] Climatic Research Unit 2006

1.1 Purpose of the Project

Based on the policy drivers of Welsh Assembly Government, this project scopes how Welsh agriculture can:

- Reduce its greenhouse gas emissions on farm from soils, crops and livestock, wastes and farm operations;
- Contribute to overall emissions reduction by growing bio-energy crops and other renewables;

Other aspects which will be covered in future work are options to:

- Reduce greenhouse gas emissions off-farm in the food chain,
- Adapt crops and livestock systems to the future effects of climate change, including extreme events,
- Contribute to the adaptation of biodiversity, water resources and flood management to the future effects of climate change.

2 Background

The Greenhouse Gas Inventory for Wales (2005) estimates that the agriculture sector emits 1.64 Megatonnes (Mt) Carbon (11%) of the total Welsh emissions of 13.7 Mt Carbon[7]. The main agricultural and land use sources of greenhouse gases are:

- 0.13 Mt Carbon as carbon dioxide (CO_2) as direct emissions from combustion of fuels, microbial decay and release of soil organic matter in aerobic conditions,
- 0.74 Mt Carbon as methane (CH_4) (60% of total Welsh emissions of methane), from ruminants, stored manures and organic materials decomposing in anaerobic conditions in soils,
- 0.77 Mt Carbon as Nitrous Oxide (N_2O) (82% of total Welsh emissions of N_2O) from microbial reactions in soils and manures, enhanced when available nitrogen exceeds plant requirements. The main source is predominantly a result of soil processes, including leaching of fertiliser nitrogen (27%), synthetic fertiliser application (19%), manure used as fertiliser (8%), ploughing in of crop residues (1%) and cultivation of legumes (< 0.1%)[8].

In addition, there is a contribution to emissions from cultivation and conversion between different land uses. This relates to the emissions and sinks from biomass of different types and the contribution of soil emissions and sinks. The relevant figures are:

- Biomass and soil; source 0.47MtC; sink 0.59MtC. Net Sink of 0.12 MtC

Also, the use of electricity by agriculture, estimated by the Carbon Trust as 0.256 Terewatt Hours, is equivalent to emissions of 0.03 MtC.

In total therefore the agriculture sector emits 2.14 MtC and absorbs 0.59MtC in Wales (1.55MtC net emission). These figures are for direct land use, and do not include any aspects of food processing and distribution. Emissions from manufacture of fertilizers would be included in the chemical sector, but in terms of farm systems, these emissions have been considered in this paper.

Nitrous oxide, methane and carbon dioxide have a global warming potential (GWP), defined as the warming influence relative to that of CO_2 and expressed as 'equivalent tonnes of carbon dioxide (t CO_2e)[9].

[7] AEA Netcen Greenhouse Gas Inventories for England, Scotland, Wales & Northern Ireland 1990 – 2004 (2006)
8 Scoping the environment and social footprint of horticultural food production in Wales, University of Wales Bangor, CALU 2007.
[9] Maunder 1992 – Dictionary of global climate change

Nitrous oxide is approximately 250 to 310 times more effective as a greenhouse gas than CO_2 and methane around 21 times, making the reduction of these emissions a key issue for agriculture[10]. The conversion figure to CO_2 equivalents used in this paper are 310 for N_2O and 21 for CH_4 as agreed and audited by the UN in reporting for the UN Framework Convention on Climate Change. This paper has expressed emissions in terms of GWP in Kt CO_2e where possible.

Agricultural mitigation options include:

- Growing and use of bio-energy in Wales – biomass and biofuels to substitute for fossil fuels
- Ways to reduce methane emissions – by anaerobic digestion and changing ruminant diets
- Ways to reduce nitrous oxide emissions – by more effective targeting of manure and fertilizer use
- Methods to manage soil carbon retention and enhancement – eg through using ECOSSE guidelines in agri-environment schemes
- Energy efficiency and microgeneration schemes for reducing emissions from agriculture.

2.1 Trends in emissions from Agriculture

Comparison of emissions trends for Welsh agriculture shows a reduction of emissions by 10.1% between the two years.

	Emissions in 2005[11]	**Emissions in 1990**
	(Kilotonnes carbon dioxide equivalent)	
Carbon Dioxide	475	527
Methane	2720	2915
Nitrous oxide	2825	2825
Total	**6020**	

(Used in Table 10.1 to show % impacts of mitigation actions on total emissions)

These changes reflect changes in the number of livestock and changes in management – i.e. how the crop or animal is managed, in terms of inputs and likely emissions potential.

DEFRA has funded a study of baseline projections for UK agriculture[12]. Policy drivers that were considered included CAP reform, Rural Development Plan, Water Framework Directive, Nitrates Directive, Integrated Pollution Prevention and Control Directive, Waste Framework Directive, Climate Change agreements,

[10] R. Jam & P Fane, Climate Change and UK Agriculture – Implications for Land Management. 2006. RICS
[11] AEA Netcen Greenhouse Gas Inventories for England, Scotland, Wales & Northern Ireland 1990 – 2004 (2006)
[12] DEFRA Project SFF0601 Baseline projections for agriculture July 2007.

and the REACH Directive. Projections to 2025 were based on a DEFRA Robust Farm Type model for future livestock and cropping patterns. The combined effects of structural changes and general improvement in management were forecast to lead to a reduction in UK emissions by 6% for methane and 3% for nitrous oxide. These reductions are based mainly on a reduction in livestock numbers, for example a reduction in dairy cow numbers is possible if annual milk yields per cow are increased.

For Wales, projected reductions in livestock were:
dairy numbers by 25%, beef numbers by 12%, sheep numbers by 6%, pig numbers by 7%, and poultry numbers by 5%. Crop areas were projected to change: Wheat – up 8%, Barley down 1%, oil seed rape up 21% and maize area up 15%.

It is important to take account of the historic trends and the projections in deciding on further interventions to reduce emissions.

3 Objectives of this Paper

1. To assess the actions which the Welsh agriculture industry can take to reduce its own emissions on-farm to contribute to the 3% annual reduction target detailed above. This report reviews the options in terms of practicality, opportunities and threats in implementation, timing and likely costs, in order to identify those actions of highest impact and easiest delivery as well as quick wins.

2. To identify levers by which the Welsh Assembly Government (WAG) can deliver emissions reductions in order to fulfil the recommendation in the 2020 report that the Welsh agricultural industry should achieve overall carbon neutral status by 2020; for example through Farming Connect, the Farm Advisory Service and agri-environment schemes.

3. To identify knowledge gaps for further research.

4 Soils and Land Use

4.1 Background

Soils and land use change make a significant contribution to the sinks and sources of GHG. For Wales in 2005, land use change to forestry and grassland sequestered 2146 kt carbon dioxide equivalent, and conversion of land to cropland and settlements led to emissions of 1899 kt CO_2 e**.** In total, land use change led to a net sink of 248 kt CO_2 e. The major components of these are:

Sinks	**kt CO_2 equivalent**
Land converted to forest	1509.5
Land converted to grassland	636.6
Total	**2146.1**
Sources	
Land converted to cropland	1046.1
Land converted to settlements	682.1
Liming cropland and grassland	46.8
Harvested wood products	123.6
Total	**1898.6**

These quantities are based on changes in biomass and soil carbon levels, and associated fluxes of GHGs. Agricultural practices are a significant driver of these changes. Mitigation opportunities exist in two main areas:

- Minimising emissions by conserving soil carbon stocks in organic soils.
- Enhancing sequestration in organic and mineral soils by grassland, woodland and wetland management

An important factor determining sinks and sources is the high soil organic content of Welsh soils, mainly associated with permanent grassland and the uplands. The most accurate estimate of the carbon stock of Welsh soils is obtained by aggregating comparable data derived from Bradley *et al* 2005[13] and Smith *et al,* 2007[14]**.** While Smith *et al,* 2007 provides a more complete estimate of total stock, the data of Bradley *et al* 2005 are currently used to calculate emissions estimates in Greenhouse Gas Inventories for Wales[15].

[13] Bradley RI, Milne R, Bell J, Lilly A, Jordan C, and Higgins c, A Soil carbon and land use database for the United Kingdom. Soil use and Management 21(40 363-369

[14] Estimating Carbon in Organic Soils – Sequestration and Emissions (ECOSSE)

[15] Greenhouse gas inventories for England, Scotland, Wales and Northern Ireland 1990-2005. AEA 2007

Based on the work of Smith *et al* and Bradley *et al*, the Welsh soil carbon stock is estimated to be 408.8 Mt Carbon, distributed within the soil types summarised in Table 4.1. Approximately half of the total soil carbon stock is located within an area of 492721 ha or 23.4% of the land surface of Wales, predominantly in upland areas and / or areas of permanent grassland. The remaining 76.6 % of Wales is covered primarily by mineral soils with low carbon content (Figure 4.1).

This paper reviews mitigation options in terms of the above soil classification. Soil type is paramount when considering impacts of agricultural operations and land use change, as different soils react differently to the same operation. So a certain operation undertaken on organic soils may reduce emissions while the same operation on mineral soils results in increased emissions.

Table 4.1. Soil carbon content of Welsh soils

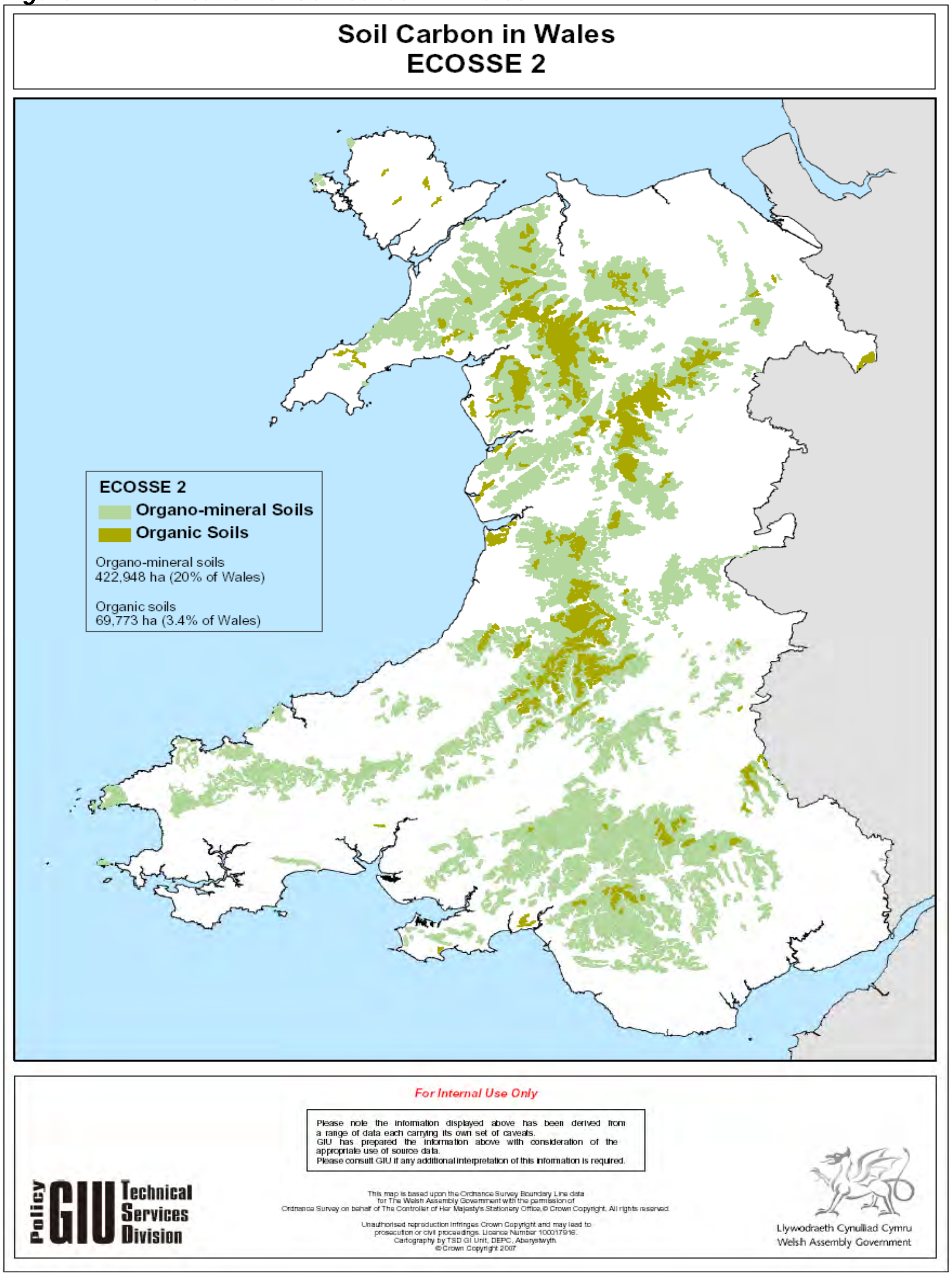
Soil Type	**Stock Mt Carbon**	**Mt CO_2 e**
Organic (greater then 40cm organic horizon)	121.3	445.1
Organo-mineral (less than 40 cm organic horizon>	74.5	271.6
Mineral (no organic horizon)	183	671.6
Unclassified	30	110.1
Total	**408.8**	**1500**

4.2 Key emission processes

Carbon dioxide is released largely by microbial respiration through the process of decay of plant litter and soil organic matter. Methane (CH_4) is produced when organic materials decompose in oxygen-deprived anaerobic conditions, such as permanently waterlogged soils. Nitrous oxide (N_2O) is generated by the microbial transformation of nitrogen nitrification, and emissions are significantly enhanced where available Nitrogen exceeds plant requirements, or under anaerobic conditions.

Agriculture and forestry operations often affect natural soil condition and processes. Examples include drainage of waterlogged organic soils, leading to aeration, increased microbial decay and an associated increase in carbon dioxide emissions. Intensive arable use of mineral soils can enhance nitrous oxide emissions due to the increased rate of nitrification associated with excess fertilizer applications. At present it is not possible to accurately account for all GHG fluxes to and from soils.

Figure 4.1 Distribution of Soil Carbon in Wales



The data presented below have high levels of uncertainty, because they have been derived from both field experiments and modelled data. Emissions from land are subject to large variations through the day, season and year, making it difficult to derive robust ‘annual average’ values. A further variable is that emissions from a specific land use/cover will depend on its history. For example, new forests will absorb carbon dioxide at a high rate in the early stages of growth through increases in soil carbon and biomass, but this absorption rate decreases as trees reach maturity. **Assuming that the relationship between loss / gain soil carbon and time is linear is simplistic,** and while this provides a way to allow yearly data to be presented, the true relationship is exponential. This is an important factor if we consider that an agri-environmental scheme typically has a life span of 10 years, whereas a change of land use from arable to woodland requires a time span of 100 years for soil carbon to achieve optimum levels. Therefore the data presented must be accepted as having a wide variation.

4.3 Actions to Reduce Emissions

In reviewing actions to reduce emissions, estimates of soil carbon loss have been based on assuming that all loss is as carbon dioxide emitted to the atmosphere. But it must be recognised that some loss of soil carbon occurs as dissolved organic carbon. Monitoring of water quality in Wales has shown that there has been a significant increase in dissolved and particulate organic carbon over the past 20 years, attributed to several factors including reduction of acid deposition and climate change.

Actions have been identified from the scientific literature in an attempt to both reinforce the recommendations and quantify the benefit of adopting options for carbon sequestration as first proposed in 1994[16]. Most recently these have been reviewed and summarised in the ECOSSE project report.

Options to retain soil carbon are very important to organic and organo-mineral soils, because of the large stock in Wales. Measures to sequester carbon and to reduce emissions of greenhouse gases are also important for mineral soils and can present the major opportunity for reducing the overall emissions from agriculture.

4.3.1 Drainage – all soils

The rate of organic matter decomposition is dependent on soil water conditions[17], and therefore altering the natural water table in organic and organo-mineral soils

[16] Dixon R.K., Brown S., Houghton R.A., Solomon A.M., Trexler M.C., Wisniewski J., 1994, The global cycle and climate change: carbon pools and fluxes, *Science,* 263, 185 – 90

[17] Goncalves JLM and Carlyle JC 1994. Modelling the influence of moisture and temperature on net nitrogen mineralization in a forested sandy soil. *Soil Biology and Biochemistry* 26(11), 1557-1564.

has impacts upon the carbon and nitrogen cycle, leading to increased emissions of GHG. While natural wet peatlands tend to be a source of CH_4 emissions, drainage leads to increased loss of carbon dioxide and greater contribution to total GHG emissions and climate change[18].

Mitigation options are:

- Any new drainage of organic soils should be avoided
- Existing drains should be blocked to reduce erosion, especially in catchments with reservoirs where colour in drainage water is a problem. Resources for this should be focused on slopes where the drainage is oldest.
- Maintaining as shallow a water table as possible should be encouraged.
- Where drainage is a necessity, areas where the water table is generally 20 cm or more below the surface in the summer should be drained in preference to constantly waterlogged areas
- Drainage should not be used to mitigate N_2O emissions on non-mineral soils: instead options such as reducing N inputs and grazing intensity should be explored.

Sequestration and reduction in emissions

Of all the ECOSSE recommendations on drainage, only restoration of wet peatlands can be quantified in terms of carbon sequestered, because the other recommendations are preventative rather than remedial measures. Watson *et al,* 2000[7] found that restored wet peatlands sequestered 0.36 – 3.6 t CO_2 e $ha^{-1}yr^{-1}$, and Kamp *et al, 2001*[20] reported a sequestration rate of 2.9 – 14.2 t CO_2 e $ha^{-1}yr^{-1}$ in re-vegetation (restoration) of wet peatlands from grasslands, and 8 – 16.8 t CO_2 e $ha^{-1}yr^{-1}$ on re-vegetation of wet peatlands from arable. The large ranges here reflect the general uncertainties in the effects of land management measures on emissions. Both options are applicable to Wales, because much of our wet peatland has undergone extensive drainage[21] and more than half of the Welsh total is considered degraded[22]. Agricultural intensification, consisting of drainage and mechanical and agri-chemical inputs has occurred throughout Wales. The conversion of semi-natural vegetation (including wet peatlands) was found to be the single most significant operation in reducing the total carbon stock of Welsh

Comment [Julie1]: Footnote reference missing?

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[19] Watson. R.T, Noble. I.R, Bolin. B, Ravindranath . N.H, Verardo. D.J, Dokken.d.j., editors. Land Use, Land Use Change, and Forestry. *Cambridge Univ Press,* 2000

[20] Kamp. T, Gattinger. A, Wild. U, munch. J. C, Methane and nitrous oxide emissions from drained and restored peat in the Danube Valley, *Verhandlungen der Gesellschaft fur Okologi,* Vol 1, Berlin: Parey:2001 . p. 193.

[21] Yeo M 1997. Blanket Mire Degradation in Wales. In: Blanket Mire Degradation. Causes, Consequences and Challenges (eds Tallis J H, Meade and Hulme P D) British Ecological Society.

[22] Jones P.S., Stevens D.P., Blackstock T.H., Burrows C.R. Howe E.A., 2003, Priority habitats of Wales, Countryside Council for Wales.

soils[2]. Adoption of this mitigation option would not be reflected in the Greenhouse Gas Inventories for England, Wales and Northern Ireland[1].

4.3.2 Grazing – all soils

Overgrazing causes significant physical damage to soil organic levels. In extreme cases this leads to a complete loss of the organic horizon, thereby reducing carbon storage and increasing greenhouse gas emissions. Upland Wales has seen an increase in grazing density from around 1-2 sheep ha^{-1} in the 1950s to an average of 5–6 sheep ha^{-1} more recently. These increases have had a detrimental effect on characteristic Welsh upland soils, both in terms of structure and organic matter content[23]. Effects of grazing are dependent on livestock type and stocking density. Direct impacts on soil are caused by a combination of trampling and nutrient addition via deposition of dung and urine. Trampling under wet conditions leads to increased N_2O emissions[24] and under dry conditions leads to increased CO_2. Emissions are greatest under wet conditions[25]. Both processes are exacerbated by the addition of nutrients via deposition of dung and urine.

To mitigate these effects:
Stocking densities need to be carefully managed to minimise negative impacts on soil organic levels.

- Heavier animals such as cattle should only be used in very limited numbers, where their less selective feeding will aid vegetation management, and not on wetter sites where they are more likely to cause significant physical damage to soil
- Stocking densities should be reduced in winter or animals removed completely, particularly on wetter sites.

Sequestration and reduction in emissions

It is difficult to quantify emissions from soils as a consequence of grazing, but limited data exists which suggests a link between increasing GHG emissions and increasing grazing density[2]. The recent report on mitigation by the Intergovernmental Panel on Climate Change (IPCC) identified that the intensity of grazing can influence the removal, growth, carbon allocation and flora of grassland thereby affecting the amount of carbon accrual in soils. Carbon accrual on optimally grazed lands is often greater than on ungrazed or overgrazed lands. But IPCC concluded that the effects are inconsistent because of the many types

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[23] Britton AJ, Pearce ISK, Jones B 2005. Impacts of grazing on montane heath vegetation in Wales and implications for the restoration of montane areas. *Biological Conservation* 125(4), 515-524.

[24] Menneer JC, Ledgard S, McLay C, Silvester W. 2005. Animal treading stimulates denitrification in soil under pasture. *Soil Biology and Biochemistry* 37(9), 1625-1629

[25] Shaw SC, Wheeler BD, Kirby P, Phillipson P and Edmunds R. 1996. Literature review of the historical effects of burning and grazing of blanket bog and upland wet heath. *English Nature Research Reports* No. 172. English Nature and Countryside Council for Wales.

of grazing practice employed, and the diversity of plant species, soils and climates involved. The influence of grazing intensity on emissions of non-CO_2 gases is not well established[26], apart from the direct emissions from grazing animals.

4.3.3 Tillage - all soils

The extent to which tillage impacts upon organic matter is dependent on soil, cropping system, manure management and climate[27]. Microbial metabolic activity has been shown to increase by up to 32% in the surface layers[28] in response to tillage operations, which incorporate organic materials and improve aeration. It has been found that this reduces organic matter content of the top 5cm by as much as 57% in comparison to conservation tillage (no ploughing or disc harrowing to 10cm depth)[29]

Impacts are also dependent on the type of cultivation carried out. Mouldboard ploughing is reported to have the most significant impact, followed by disc ploughing, with conservation ploughing or harrowing being most similar to no tillage regimes[30]. In addition to increased CO_2 emissions, N_2O emissions increase as a consequence of stimulated microbial activity following cultivation.

There have been only limited studies of tillage practices in the UK, with most looking at zero tillage rather that minimum tillage practices. The best estimate of carbon storage potential of zero tillage under England and Wales conditions is 1.1 (+/- 0.65) t CO_2 e $ha^{-1}yr^{-1}$, with reduced tillage having about half of this potential. These must be regarded as only the <u>initial</u> rate of increase (over less than 20 years), with a decline in the rate of carbon storage after this time. This accumulation process is finite. It is also reversible, if the practice is not continued permanently. Ploughing will release much of the stored carbon.

Overall GHG emissions may increase from reduced tillage practices as a result of increased emissions of nitrous oxide, which offset the carbon dioxide storage.

The potential of minimum and zero tillage operations in mitigating CO_2 emissions may be greater for mineral soils because there is the potential for greater soil

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26 IPCC 4th Assessment Report. Working Group 3. Mitigation of Climate Change. Cambridge University Press 2007

27 Bhogal A, Chamber B, Whitmore AP, Powlson DS. The effects of reduced tillage practices and organic material additions on the carbon content of arable soils. DEFRA report SP0561. 2007

28 Balota, E.L, Filho, A.C., Andrade, D.S., Dick, R.P. 2004. Long-term tillage and crop rotation effects on microbial biomass and C and N mineralization in a Brazilian Oxisol. *Soil and Tillage Research* 77, 137-145.

29 Salinas-Garcia JR, Velazquez-Garcia JD, Gallardo-Vladez A, Diaz-Mederos P, Caballero-Hernandez F, Tapia-Vargas LM, and Rosales-Robles E 2002. Tillage effects o microbial biomass and nutrient distribution in soils under rain-fed corn production in central-western Mexico. *Soil and Tillage Research* 66(2), 143-152.

30 Wright AL, Hons FM, Matocha Jr. JE. 2005. Tillage impacts on microbial biomass and soil carbon and nitrogen dynamics of corn and cottom rotations. *Applied Soil Ecology* 29, 85-92.

carbon accumulation. For example in N America, carbon-trading schemes are currently in place based on forgoing the option to cultivate soils. Such schemes are specifically concerned with soil carbon and do not take into account the consequences of zero tillage on the other GHG emissions.

Recommended mitigation options are:

- Zero-till regimes should be encouraged **only on organic soils**
- Deep ploughing should not be allowed on soils with high carbon contents.
- Winter ploughing should be avoided to reduce erosion risk and effects of freeze-thaw cycles on bare soil: instead where necessary, ploughing should be carried out as close to new crop sowing as possible to minimise soil exposure.

While the evidence clearly illustrates the benefits of adopting conservation tillage on organic and organo-mineral soils, it is not possible to provide a figure due to the lack of supporting data for tillage cycles within grassland systems and the complex relations between the dependent factors. Adoption of this mitigation option would not be reflected in the Greenhouse Gas Inventories for England, Wales and Northern Ireland[1]. Further work is being commissioned by DEFRA to gain a better understanding of tillage options in relation to mitigation.

4.3.4 Improved grassland – organic and organo-mineral soils

Conversion of unimproved land to improved short-term leys, comprising drainage, removal of natural vegetation, cultivation, inputs of mineral fertilizer and liming has been found to cause fast loss of stored carbon[31]. The rate of loss is subject to variation dependent on several factors including soil, climate and extent of improvement. When organic soils are converted to managed grassland, this reduces the sequestration rate typically by around 10.9 – 18.3 t CO_2 e $ha^{-1}yr^{-1}$ [32] and leads to increased emissions of 5.5 – 12.8 t CO2 e $ha^{-1}yr^{-1}$ [33]. The IPPC Tier 3 reporting method uses default figures of 400 tC ha^{-1}, (1464 t CO2 e ha^{-1}) averaged over 50 years, on converting organic soils supporting unimproved vegetation, to improved grassland.

Mitigation options include:

- Discouraging conversion to improved grassland on organic soils
- Where possible, blocking drains on existing grassland to restore a high water table.

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[31] Bryne KA, Chonjicki B, Christensen TR, Drosler M, Freibauer A, Friborg T, Frolking S, Lindroth A, Mailhammer J, Malmer N, Selin P, Turunen J, Valentini R, Zetterberg L (2004) *EU Peatlands: Current Carbon Stocks and Trace Gas Fluxes*. Carbo-Europe Report , Christensen TR, Friborg T (eds.)

[32] Schipper, L.A., McLeod, M. 2002. Subsidence rates and carbon loss in peat soils following conversion to pasture in the Waikato Region, New Zealand. *Soil Use and Management* 18, 91-93.

[33] Bryne KA, Chonjicki B, Christensen TR, Drosler M, Freibauer A, Friborg T, Frolking S, Lindroth A, Mailhammer J, Malmer N, Selin P, Turnunen J, Valentini R, Zetterberg L (2004) *EU Peatlands: Current Carbon Stocks and Trace Gas Fluxes.* Carbo-Europe Report

- If blocking drains completely is not feasible, maintaining as shallow a water table as possible will reduce carbon losses.
- Minimising disturbance to the soil – using a permanent crop to avoid tillage, and minimising or ceasing lime and fertiliser inputs.

Sequestration and / or reduction in emissions
Within Wales there are 60,000ha[34] of land under temporary grassland (improved grassland ploughed within a 5 year cycle), of which 2500ha is located on organic and organo-mineral soils. Based on loss rates of around 5.5 – 12.8 t CO2 e $ha^{-1}yr^{-1}$, the estimated total emissions from the 2500ha temporary grassland on these soils is between 13.7 Kt CO2 e yr^{-1} and 32 Kt CO2 e yr^{-1}. Reversion of improved grassland to semi-natural habitat would stop this rate of loss, and lead to further net reduction of emissions through sequestration of 11.9 Kt CO2 e yr^{-1} (IPCC default figures. Another estimate is that the sequestration rate is 27.5 –45.75 Kt CO2 e yr^{-1} (ref No 25)

4.3.5 Arable – organic and organo-mineral soils

Conversion to arable land use is the worst-case scenario for organic soils, due to the high level of disturbance, coupled with lack of subsequent soil carbon storage because of repeated tillage. Losses of 14.6 – 29.2 t CO_2 e $ha^{-1}yr^{-1}$ (4-8 t C ha^{-1} yr^{-1}) are believed to be a representative figure.

As well as losing stored carbon rapidly, organic soils used for arable crops emit significant levels of N_2O. A range of 5.4-14.1 kg N_2O-N ha^{-1} yr^{-1} has been reported from organic soils being used to grow barley. It has been estimated that while organic soils under arable land use account for only 10% of all agricultural soil in Finland the land is responsible for 25% of national N_2O emissions.

For mitigation:
- Conversion to arable land use should be strongly discouraged on soils with high carbon contents.
- Ideally, existing arable land on organic and organo-mineral soils should be restored to its natural water level and vegetation.

Sequestration and / or reduction in emissions
Based on emission rates of 14.6 – 29.2 t CO_2 e $ha^{-1}yr^{-1}$ and a total area of 1500ha of arable land located on organic soils, total emissions are in the range of 21.9 – 43.9 kt CO_2 e yr^{-1}. Based on the ECOSSE methodology, conversion of arable land to more natural permanent pasture would reduce emissions by 21.9 – 27.9 kt CO_2 e yr^{-1}. IPPC Tier 3 methodology does not distinguish between arable and improved grassland and therefore the default figure for conversion is 4.7 t CO_2 e

[34] Agricultural Statistics for Wales 2005

$ha^{-1}yr^{-1}$ based on a 300 yr period. Given that within Wales 1500 ha of organic soils are under arable use, conversion to natural vegetation would give a total reduction of 7.1 kt CO_2 e yr^{-1}.
As with conversion of improved grassland to natural vegetation this action would be reported within the AEA GHG inventory, giving a reduction of 7.1 kt CO_2 e yr^{-1} .

4.3.6 Organic matter incorporation – mineral soils

Currently, approximately 90 million tonnes of farm manures, 3-4 million tonnes of bio-solids and 4 million tonnes of industrial 'wastes' are applied annually to agricultural land in the UK. It is questionable whether the application of bio-solids represents genuine additional carbon compared with a present-day baseline of use of organic materials on land. Application of compost and paper crumb potentially offers GHG emissions savings through the diversion of materials from landfills – a major source of methane emissions. It is uncertain as to increase the potential to incorporate organic matter through time as soils reach a natural equilibrium in organic content, where essentially any further increase greatly inhibits the ability of the soil to deliver certain functions.

Sequestration and / or reduction in emissions
Results from four ENVIROS study sites suggest that the application of green waste compost to arable land in England and Wales has the potential to increase Soil Organic Content (SOC) by 60 kg $ha^{-1}yr^{-1}$ per tonne of compost dry solids, applied at typical application rates of 250kg ha^{-1}. This can only be regarded as the initial rate of SOC increase (<20 yr) as SOC accumulation rates decline with time.

Additional benefits of diverting green waste from landfill are also achieved in adopting this mitigation option. Also due to the nutrient delivery associated with applying green waste compost a reduction in synthetic fertilizers is achieved. Given the total arable crop area of Wales is 64988ha[35], a potential increase of 3899 t yr^{-1} of Soil Organic Matter (SOM) could be achieved. At this stage it is not possible to calculate the emissions reductions resulting from diversion from landfill. It is also unclear if the action would impact upon the total GHG flux. The primary result of this action would be to increase the total carbon stock of soil, although there are issues that this would reach a limit beyond which the material would be mineralised and emitted to the atmosphere.

Comment [Julie2]: Correct figure?

An important factor is that SOM and SOC are not the same and the above figure is not directly convertible to CO_2 equivalents.

4.3.7 Organic farming – all soils

[35] Agricultural Statistics for Wales 2005

Additional research is required on organic farm systems because recent studies have reached conflicting conclusions. There is evidence that in certain circumstances organic farming has a positive impact in terms of soil carbon. However from life cycle analysis of an organic system, although emissions per hectare may reduce, GHG emissions per unit of produce are higher for organic systems than for conventional systems[36] due to the reduction in yield/ha in organic systems. Further study based on life cycle analysis principles is required to fully understand the positive and negative aspects of organic versus conventional farming.

4.3.8 Land use change – all soils

Mitigation options for conversion of arable land to permanent grassland, arable land to woodland and permanent grassland to woodland all represent significant potential in terms of mitigating GHG emissions. Equally, reverse changes cause increased GHG emissions. The change from arable to woodland represents the largest net mitigation option for mineral soils.

Table 4.2 and Table 4.3 summarise the IPCC estimates of equilibrium carbon contents expressed as carbon dioxide equivalents. Emission rates are estimated as **linear** losses over 50 years or **linear** gains over 100 years – a considerable simplification of the actual processes.

Table 4.2

Land use	**Mineral soils England and Wales (t CO_2 e $ha^{-1}yr^{-1}$), loss averaged over 50 years and gain over 100 years**
Natural or woodland	732
Farm grass	658
Arable	475
Built over (Settlements)	366

Table 4.3

Land use	**Organic soils England and Wales (t CO_2 e $ha^{-1}yr^{-1}$), loss averaged over 50 years and gain over 300 years**
Natural or woodland	4026
Farm grass and Arable	2562

For example on mineral soils, if a change takes place from woodland to grassland the difference is 732-658 = 74 t CO_2 e ha^{-1} over 50 years, equivalent to a loss of

[36] Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra.

1.5 t CO_2 e ha^{-1} yr^1 ,whereas the change from grassland to woodland leads to a sequestration rate of 0.73 t CO_2 e ha^{-1} yr^1 over 100 years. An important factor is that loss is a rapid process and sequestration is a slow process: this is most marked for organic soils.

The relationship between loss / gain and time is exponential and variable depending on site conditions and species. To allow generic figures to be presented it has been assumed that fluxes for sinks and sources operate at a constant rate over time, with homogenous site conditions.

Table 4.4

Land use	Mineral Soil ha	Organic soil ha
Arable	50500	1500
Farm Grass <5 yr rotation	57500	2500

Table 4.4 land use derived from the Single Farm Payment data 2006.

The default figures within Table 4.2 and 4.3 allow calculations to be made which are reportable (within Wales' GHG inventory). Change from arable to natural habitat / woodland for the total area of arable on mineral soils within Wales would sequester 129.7 kt CO_2 e yr^{-1} for 100 years. Change from arable and farm grass to natural habitat / woodland for the total area of these land use types in Wales would sequester 19.5 kt CO_2 e yr^{-1} for 100 years.

In addition to the increased soil carbon content on conversion of arable to woodland a significant carbon sink occurs within the woody bio-mass. This is dependent on species, and ranges from 13.9 t CO_2 e ha^{-1} yr^1 for slow growing species e.g. oak, to 36.6 t CO_2 e ha^{-1} yr^1 for fast growing species, e.g. conifer, over a time span, which is species dependent. The life cycle sequestration figure for an average UK woodland is 366 – 732 t CO_2 e ha^{-1} over its lifetime.

For the scenario of conversion of all arable land on mineral soils to woodland, the combined biomass and soil carbon sinks would potentially sequester 701.9 kt CO_2 e yr^1 within woody biomass (using the lower range estimate of 3.8 t C ha^{-1} yr^{-1}) (13.9 t CO_2 e ha^{-1} yr^1). Combined with the 129.7 kt CO_2 e yr^1 within the soil, this gives a total of 831.65 kt CO_2 e yr^1. The estimate may not be accurate because it combines aspects of the GHG Inventory soil methodology and woodland biomass accumulation rates. An assumption has been made that the life cycle of an average Welsh woodland is 100 years to allow the figures to be combined.

It is essential to stress that the figures are estimates, and may differ from the default numbers in the inventory method. Also the estimates are based on linear rates of sequestration, which is far from the real situation.

For farm scenarios, conversion of 10 ha of arable to woodland on mineral soils would provide an annual sink of 164.7 t CO_2 e yr^{-1}. Alternatively,

conversion of 10 ha of improved grassland to woodland would provide an annual sink of 146.3 t CO_2 e yr^{-1}. For organic soils, a change of land use from arable / farm grass to natural vegetation would provide a annual sink of 178.6 t CO_2 e yr^{-1}, based on current evidence of the long term benefit of afforestation of organic soils. Clearly the conversion of grassland and arable to woodland on mineral soils or natural vegetation on organic soils provides an opportunity for single farms to offset their carbon emissions thus contributing to achieving carbon neutrality. This mitigation option represents the largest return in terms of sequestration, and additional benefits could also include flood risk mitigation and enhanced ecological connectivity.

4.4 Key constraints and knowledge gaps

As noted earlier the effect of land management practices and changes on emissions are far from being quantified. Further research is required to quantify the effects of grazing intensity and type, and the effects of land-use changes on combined emissions in soils and biomass. Research is also required on organic farm systems and minimum / zero tillage, due to the conflicting conclusions reached by recent studies.

4.5 Recommendations and summary

Table 4.5 summarises the emission and sequestration rates for the range of land management options **assuming constant rates over time. The rates should be used to rank management options, not as reliable numbers because of the uncertainties in measurements and the range of conditions over which they are measured.** Expansion of wetlands, woodlands and semi-natural grasslands are the main ways that soil carbon can be maintained and sequestration can be increased.

Table 4.5

Management Option (as reported in the scientific literature)	**Estimated emission/sequestration rate (t CO_2 e ha^{-1} yr^{1})**
Grassland to wetland	- 2.9 to -14.2
Arable to wetland	- 8 to -16.8
Zero tillage (organic soils)	- 1.1
Natural vegetation to improved grassland (organic soils)	10.9 to18.3
Improved to semi-natural grassland (organic soils)	- 4.8
Arable soils (on organic soils)	14.6 to 29.2
Arable to grassland (organic soils)	- 4.7
Arable to grassland (mineral soils)	- 1.82
Grassland to woodland – soil only	- 0.73
Arable to woodland – soil only	- 1.82

Oak woodland - biomass only	- 13.9
Conifer woodland – biomass only	- 36.6

Note: Negative numbers signify sequestration: positive numbers signify emissions
All numbers are subject to a large range of uncertainties

From a Wales GHG inventory perspective (see Tables 4.2, 4.3 & 4.4) only conversion of grassland to woodland, arable to woodland, and arable to grassland count in terms of emissions reduction. The reverse conversions contribute to emissions increases. The primary reason for this is that the GHG inventory methodology fails to consider detailed options, which are not quantifiable due to a relatively poor understanding of GHG fluxes. Addressing these knowledge gaps and increasing the sensitivity of the inventory methodology would allow some of the mitigation options presented in this paper to be monitored in terms of tracking their contribution to meeting Welsh GHG emissions targets.

On organic soils adoption of ECOSSE recommendations would limit the loss of soil carbon and in certain instances (such as land use change) enhance the stock of soil carbon.

On mineral soils incorporation of green waste compost offers some potential in enhancing the carbon stock of soils but the overall mitigation benefit is based only on diversion of bio-degradable materials from landfill. There are also significant limitations with regard to permanence of the stored carbon.

Given the probable future competition for use of the small % area of land in Wales[37] suitable for cropping, it is unrealistic to consider that improved grassland and arable land will be available to convert to semi-natural habitat and woodland in order to reduce GHG emissions. In practice, there could be an increase of land under crops, particularly for field-scale horticulture and bio-energy.

For both organic and mineral soils, land use change by afforestation of marginal land to create farm sinks provides the largest potential benefit in terms of carbon sequestration. Also this would be reflected within the inventory. Such an option could be central to delivering the 2020 aspiration of Welsh agriculture becoming carbon neutral. It is expected that such a target will only be achievable within certain systems in certain locations. Additional research is required to assess the impacts of other parameters such as vegetation types within the farm system.

[37] Welsh Agricultural Statistics 2006

5 Manures and Fertilisers

5.1 The Use of Fertilisers and Manures

Livestock manures and slurries have been used since the beginning of agriculture as a source of plant nutrients. However their method and timing of application has not always been optimal, leading to a loss of nutrients, including nitrogen, to the environment. The use of fertilisers and manures in agriculture has been identified as an important source of greenhouse gas emissions[38].

5.2 Key Emissions from Fertilisers and Manures related to Wales

5.2.1 Nitrous Oxide

67% of the UK's nitrous oxide emissions come from agriculture, partly from livestock manures, but mainly from the use of artificial fertiliser. The manufacture, distribution and application of fertilisers is energy intensive and results in significant emissions. Every year, over half the total 'new' nitrogen introduced into the UK economy comes from agricultural fertilisers. In 2006 the Agricultural Industries Confederation estimated that UK fertiliser consumption was 1.003 million tonnes of nitrogen[39]. Given that on average around half of the fertiliser applied is taken up by the growing crop, and the rest lost to the environment, fertiliser is a major contributor to the reactive nitrogen in the environment. The British Survey of Fertiliser Use (2006)[40] states that the overall nitrogen use on all crops and grassland peaked at 144kg ha^{-1} between 1983 and 1987, but has dropped every five year period since then. In the period 2003 to date the average amount used is 109kg ha^{-1}, reflecting a downward trend observed on both grassland, and to a lesser extent, on tillage crops. This is due in part to an increased reliance on livestock manures for plant nutrients.
Nitrous oxide is produced when nitrates are converted by microbial activity in anaerobic conditions. Direct emissions of N_2O are produced when nitrates are present, from excess application of inorganic fertilisers and manure applications to land, and from manure storage. Indirect emissions of nitrous oxide occur from leaching and soil runoff.

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[38] Stern Report
[39] Agricultural Industries Confederation Fertiliser Statistics Report, 2007
[40] The British Survey of Fertiliser Practice for 2006 (2007) Defra

Deleted: Nitrogen UK, (2005), Warwick HRI,

GHGI Figures for Wales (2005)[41] show the sources of emissions to be:

1) Leaching of fertiliser nitrogen and applied animal manure to ground and surface water (29%) = **767.9** kt CO_2 equivalent
2) Synthetic fertiliser application (19%) = **503** kt CO_2 equivalent
3) Manure used as fertiliser (9%) = **238.3** kt CO_2 equivalent
4) Manure solid storage and dry lot = **112.7** kt CO_2 equivalent
5) Manure liquid systems = **5.1** kt CO_2 equivalent
6) Other manure = **7** kt CO_2 equivalent.

Giving a **total global warming potential (GWP)** of N_2O emissions from manure and fertiliser use in Wales of **1634 kt CO_2** equivalent.

Table 5.1 shows the emissions of NO_2 from synthetic fertilisers used on different farm types in Wales. The figures are derived from The British Survey of Fertiliser Practice (2006), Welsh Agricultural Statistics and the Farm Business Survey, and are calculated using the following methodology:

According to the British Survey of Fertiliser Practice the N input in Wales in 2006 equates to an average of **78kg ha^{-1}** applied to the 1,610,000ha of crops and grass[42]. In practice, however, there are large areas of agricultural land, predominantly unenclosed coastal and hill land, where N is not applied at all. This average gives a **total N applied in Wales (2006) of 125.6 kt.**

The IPCC methodology as explained in Annex 1 of the CLIO report[43] was used to estimate the emissions from application of this fertiliser. It is necessary to make a 10% reduction in N applied/ha to account for losses as ammonia and Nitrogen oxides to the atmosphere, giving a rate of **70.2kg ha^{-1}.**
(10% reduction is used for fertilisers, 20% for manures, due to the higher rate of volatilisation - Clio report)

N emitted is 1.25% of the adjusted application rate of N. After applying this adjustment and then using a) the factor of 44/28 to convert nitrogen to N_2O weights and b) the GWP of 310 to convert the result to CO_2 equivalents the emissions figure is **688.75 kt CO_2 equivalent.**
This figure is considerably higher than the **503 kt** referred to in the inventory for 2005. The 503 kt is derived from using a figure of 81.7kt N applied in Wales. The differences show the lack of precision in the estimates.

[41] Greenhouse gas inventories for England, Scotland, Wales and Northern Ireland 1990-2005. AEA 2007
[42] The British Survey of Fertiliser Practice for 2006 (2007) Defra

[43] Viner, D; Sayer, M; Uyarra, M; and Hodgson, N; 2006, Climate Change and the European Countryside: Impacts on Land Management and Response Strategies; Report prepared for the Country Land and Business Association (CLIO Report).

Table 5.1 – Analysis of emissions per ha for agricultural land type, Wales
NB. These figures are for stand-alone land use types and as such will not produce a comprehensive total for Wales.

Farm Type / Land Use	**Area of Land (ha)**	**Kg of fert N per ha[5] (less deduction of 10% for Nox and NH3)**	**Kg N_20 (x1.25%x44/ 28) emitted ha^{-1}**	**Total N applied**	**Emissions, kt $C0_2e$ (Wales)**
All agricultural land in Wales, Crops, permanent grass and rough grazing	1,610,000[44]	78 (70.2)	1.38	125,580t	688.75kt
Crops (tillage) and permanent grass	1,202,000[45]	98 (88.2)	1.7	117,796t	645.56kt
Crops (tillage) land	64,988[46]	134 (120.6)	2.4	8,708t	47.72kt
Dairy	271,310[47]	136 (122.4)	2.4	36,898t	202.21kt
Hill beef and sheep	420,921[48]	53 (47.7)	0.9	22,309t	122.26kt
Lowland livestock	242,151[49]	68 (61.2)	1.2	16,466t	90.24kt

There are different emission factors used to calculate N_20 from different waste management systems per kg N excreted. The method for calculating this is explained in detail on page 147 of the CLIO report, and could be used to calculate emissions for the farm type scenarios used in other chapters of this report. It is important to note and consider that different waste systems result in differing emission factors.

The typical N_2O emission factor for applying manures to land is 1.96%.[50]
Green manures also have nitrogen fixation utilisation together with the ploughing in of crop residues and should be taken into account.

[5] Figures from British Survey of Fertiliser Practice, Welsh disaggregation
[44] Farming Facts and Figures, 2007, refers to all agricultural land less woodland area
[45] Farming Facts and Figures, 2007, arable land plus permanent grass
[46] Farming Facts and Figures, 2007, total crops (tillage less bare fallow)
[47] 2005 no of dairy holdings x average holding size effective area (Farm Business Survey, 2006/2007)
[48] As per above footnote 37
[49] As per above foot note 37
[50] Min till report

5.2.2 Methane

It is estimated that 36% of the UK methane (CH_4) emissions come from agriculture[51]. The majority, (approx. 84%) of this is from enteric fermentation in the digestive system of livestock, with the remaining 16% from manure management, extensive livestock grazing on habitats[52], and organic materials decomposing in anaerobic conditions in soils and wetlands. For example, dairy cows produce 115kg methane per head per year by enteric fermentation, compared with 13kg per head per year from manure[53]. Storage of manures also gives rise to methane production when the availability of oxygen is restricted.

GHGI Figures for Wales (2005) show the sources of emissions to be:

1) Dairy cattle wastes = **141.1** kt CO_2 equivalent
2) Other cattle wastes = **88** kt CO_2 equivalent
3) Sheep, goats and deer wastes = **22.9** kt CO_2 equivalent
4) Other livestock wastes (of which Broiler hens make the most significant contribution) = **14.9** kt CO_2 equivalent

Giving a **total global warming potential (GWP)** of CH_4 emissions from manure and fertiliser use in Wales of **266.9kt CO_2 equivalent**.

5.2.3 Carbon Dioxide

Carbon dioxide is emitted when fossil fuels are used to produce inorganic fertiliser and during its application to land by machinery.

[51] NERA Economic Consulting. 2007. Market mechanisms for reducing GHG emissions from agriculture, forestry and land management. DEFRA
[52] Monteney G –J, Bannink A and Chadwick D. (2006) Greenhouse abatement strategies for animal husbandry, Agriculture, Ecosystems and Environment 112 163-170
[53] Methane UK, 2006, Environmental Change Institute.

Table 5.2 - Shows the CO_2 emissions to air from the production of common fertiliser types.[54] ***(full table at Annex I)***

Fertiliser	% used in England & Wales	Reference Unit	Primary Energy used, MJ	GWP_{100}, kg CO_2 e	CO_2 (total), to air, kg
Ammonium Nitrate (AN) as N	37	1 kg N as N	41.0	7.2	2.7
Urea (UN) as N	5.6	1 kg N as N	49.2	3.5	3.3
Calcium Ammonium Nitrate (CAN) as N	0.4	1 kg N as N	42.8	7.4	2.8
Ammonium Sulphate (AS) as N		1 kg N as N	42.4	3.0	2.8
Mean N fertiliser for grassland as N		1 kg N as N	41.9	7	3
Compost-N		1 Kg	8.6	0.5	0.5

Note: emissions can be converted to per kg of product by recalculating according to %N per kg of product. For example, Ammonium nitrate is 34% N, therefore you need to apply 2.9kg AN to apply 1kg N. This gives an emission of 0.9kg CO_2 per kg AN used.

5.3 Actions for mitigation of the key emissions

Emission reduction options in relation to fertiliser and manure management fall into a number of key categories to include appropriate fertiliser application practice, manure & livestock management, land management and consideration of alternative management to include alternative fertilisers. None of the categories are independent of each other nor are they independent to those related to livestock management, cropping management, grazing management, soil management, bio energy and bio fuel cropping. The management of interactions between the different methods is frequently the key to successful GHG emission reduction[55].

From our review of the research, a number of mitigation methods have been identified. **Table 5.3 shows the potential emission reductions achievable**. The hypothetical potential effects have been estimated where possible.
The potential quick win methods identified as practical considerations for on farm reduction of emissions relating to fertiliser and manure use include:

[54] Williams, AG; Audsley, E and Sandars, DL (2006), Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main report, Defra research project IS0205. Bedford: Cranfield University and Defra.

[55] J.M Moorby, D. R. Chadwick, D. Scholefield, B. J Chambers, J. R Williams (2007). A Review of Research to Identify Best practice for Reducing Greenhouse Gases from Agriculture and Land Management. IGER. ADAS

- Nutrient Management practices: not exceeding the crop N requirements, applying rates based on precise estimation of crop needs.
- Manure management: making full allowance for the N supply provided by organic manure, spreading manure at the appropriate times and at correct application rates (to include precision farming).
- Ensuring appropriate storage of manure on holdings and considering converting to a slurry based system
  (long term potential methods are noted in summary in point 5.3.5)

5.3.1 Nutrient Management - Ensuring that fertiliser application rates do not exceed the crop N requirements and that application rates are based on precise estimation of crop needs.

The essence of good nutrient management and fertiliser use is to ensure that the necessary quantities of the essential crop nutrients are available when required for uptake by the crop and that losses of nutrients to the environment are minimised. Any application of fertiliser which exceeds the crop nutrient requirement or which is not properly applied at the appropriate time, will waste money and increase the risk of pollution and emission losses.[56]

Mineral fertiliser should only be applied when all the other sources of nutrients are insufficient to meet the crop requirements.[57] Any applications over and above the crop requirements are economically unjustified and can aggravate problems such as lodging and disease. A fertiliser recommendation system/practice can be applied to all farming systems to confirm the correct nutrient application required this would ensure that nutrients are only applied when the supply from other sources is insufficient. It should be noted however that although this method could result in emission and cost savings this method is particularly effective in intensive grassland, arable and horticulture systems and less effective for extensive grassland systems due to the volumes of fertilisers applied.

In addition to ensuring that the correct volumes of inorganic fertilisers are applied, regular testing of fertiliser equipment would contribute to greater resource efficiency and more sustainable farming overall. Improving spreader efficiency and related measures would contribute to the potential reduction in fertiliser use and the potential emission reduction achievable as a result. Potential reduction levels are shown in Table 5.3.

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[56] RB209, MAFF, 2000

[57] J.M Moorby, D. R. Chadwick, D. Scholefield, B. J Chambers, J. R Williams (2007). A Review of Research to Identify Best practice for Reducing Greenhouse Gases from Agriculture and Land Management. IGER. ADAS

5.3.2 Manure management - Ensuring that full allowance is being made of the N supply provided by organic manures

Organic manure provides a valuable source of organic matter and nutrients. Application to land allows them to be used for the benefit of crops, which can result in large savings and reduce the risk of losses. Losses following an application of organic material can lead to environmental pollution due to N and P losses to watercourses, as well as gaseous emissions of ammonia and N_20 to the atmosphere. Making proper allowances for the nutrients in manure will result in a reduction in mineral fertiliser inputs.

This method is most applicable to intensive grassland and arable systems, although it is effective wherever mineral fertiliser is used as a top up to the nutrients supplied in organic manure. The potential effect of this method depends on the reduction in mineral N fertiliser and the quantity of manure N supply. Fertiliser recommendations, training and advice on sampling and analysis would increase awareness of the potential savings. Secondary benefits of NH_3 reduction could be achieved if manure is more rapidly incorporated into arable land or applied using injection methods rather than being broadcast. Injecting in spring and after first cut silage and on grass inland during the season allows cattle to graze the land far quicker and the nitrogen cycle loses are far less.[58]

Slurry manure has a high content of readily available N, compared with a straw based manure. Avoiding application of high readily available N manure when there is little or no crop demand reduces the risk of direct N_20 losses. The potential emission reductionlevels are presented in Table 5.3.

5.3.3 Ensure that slurry is spread at the appropriate times and at correct application rates

All applications of fertilisers should only be undertaken when the crop is able to take up and make best use of the nutrients being made available. As a general principle, nitrogen should be applied at the start of periods of rapid crop growth and nitrogen take up. Avoiding time delays between N application and plant N up take can improve N use efficiency.[59]

Recognised "good agricultural practice" is to apply slurry in relation to crop demand. This reduces the quantity of excess nitrogen in the soil, which is at risk of NO_3 leaching or N_2O emissions (Thorman et al 2007, NERA). However, farmers are often under pressure to empty slurry stores in the autumn / early winter period to prepare for the housing period, or during winter because of inadequate storage facilities. Such autumn / winter slurry applications result in excess soil nitrogen.

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[58] H Evans. 24th August 2007, Watch your nitrous oxide to reduce your carbon footprint. Farmers Weekly

[59] Cole, C.V et al. 1997 Global estimates of potential mitigation of greenhouse gas emissions by agriculture. Nutr, Cycl Agroecosyst, 49, 221-228

Because this season is also associated with increased soil moisture, low crop nitrogen-uptake, and temperatures warm enough for nitrification / denitrification, significant emissions of N_2O can occur. Emissions are far lower if slurry is applied in the spring, when growing crops actively remove slurry nitrogen.[60]

In the limited work that has been undertaken on free-draining grassland soils, N_20 emissions from spring slurry applications were half those from late autumn / winter applications (i.e. a reduction from approximately 1kg to 0.5kg direct N_20, or 247 kt CO2e nationally)[61]. Changing to spring slurry applications (from autumn / winter) would require investments in additional slurry storage. The increased storage time would result in increased CH_4 emissions, offsetting some of the benefit of reduced N_2O emissions.

The development and application of a mineral fertiliser N application timing strategy could ensure the avoidance of large amounts of $N0_3$ in the soil under wet and warm conditions.[62] This method would be dependent on site specific tests and may not be easy to apply within the day to day management of individual farm holdings.

5.3.4 Ensuring that storage of manure is appropriate.

Recent DEFRA research has identified that some of the most cost efficient measures to reduce on farm ammonia emissions include covering poultry manure stores, immediate incorporation of manure into arable land and allowing cattle slurry lagoons to crust over[63]. Storing and handling the manure in solid rather than liquid form can suppress CH_4 emissions, preliminary evidence suggests that covering manure heaps can reduce N_20 emissions.[64]

Converting from a solid manure based system to one that is slurry based, results in little or no possible slurry being converted into $N0_3$, resulting in lower N_20 emission. This method is costly and only applicable to sectors with housed stock that currently handle all or part of their manure as solid manure

Methane emissions from manure stored in lagoons or tanks can be reduced by cooling or covering sources or by capturing the CH_4 emitted.[65] Compacting solid manure heaps maintains anaerobic conditions, reducing N_20 emissions, however

60 NERA Economic Consulting. 2007. Market mechanisms for reducing GHG emissions from agriculture, forestry and land management. DEFRA

61 NERA Economic Consulting. 2007. Market mechanisms for reducing GHG emissions from agriculture, forestry and land management. DEFRA

62 J.M Moorby, D. R. Chadwick, D. Scholefield, B. J Chambers, J. R Williams (2007). A Review of Research to Identify Best practice for Reducing Greenhouse Gases from Agriculture and Land Management. IGER. ADAS

63 DEFRA research paper AM0101 (2004) National Ammonia reduction strategy evaluation system, ADAS, J Webb

64 refer to footnote 16 & 17.

65 P Smith et al, Greenhouse gas mitigation in agriculture. 2007. The Royal Society B

the anaerobic conditions created by compaction can result in higher levels of CH_4 emissions. There would also be high health and safety risk associated with a relatively small emission reduction.[66]

5.3.5 Long term potential mitigation measures

Measures which could be implemented in the future or are still at development stage and require further investigation include the following:

- Using the least emitting form of N Fertiliser – Switching from ammonium nitrate to urea at certain times of the year can hold significant potential for emission reduction.[67]
- Applying other forms of fertiliser e.g. green manure practices (applying other forms of fertiliser to land to reduce reliance on artificial fertilisers) – legumes can provide between 100-250kg Nha^{-1} and as much as 350kg Nha^{-1}.[68]
- Better management of nitrogen flows, including improving soil drainage to reduce water logging and considering substituting clover for synthetic nitrogen fertilisers.
- Applying anaerobic digestion practices – (processing methane from slurries and manure in digesters, which capture the CH_4 for burning). The EU MIDAIR study concludes that of the manure treatment options evaluated, anaerobic digestion has the greatest potential for greenhouse gas mitigation, as not only can it substitute for fossil fuel use, but the partially composted digestate, provides a readily available N fertiliser source.[69] This mitigation method is discussed in detail in the bio-energy section.
- Using Nitrification or Urease inhibitors with urea or ammonia compounds and slow releasing fertiliser forms – (addition of chemicals which reduce the rate of conversion of NH_4 to $N0_3$, increasing N efficiency and reducing losses).
- In New Zealand, nitrate inhibitors based on Dicyandiamide and 3,4 dimethylpyrazole phosphate (DMPP) have been added to animal slurries and soils to inhibit loss of nitrate to leaching and to nitrous oxide. The rationale is that the rate of nitrification is reduced so that nitrate is formed at a rate that the crop can use, increasing nitrogen efficiency and reducing N_2O and nitrate emissions. However recent research in New Zealand has shown that nitrification inhibitors can be extremely effective when added to mineral

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[66] NERA Economic Consulting. 2007. Market mechanisms for reducing GHG emissions from agriculture, forestry and land management. DEFRA

[67] Nitrous oxide emissions from agricultural soils, and the potential for their reduction. DEFRA project CC0233, 2001

[68] Rochon J J, Doyle C J, Greef J M, Hopkins A, Molle G, Sitzia M, Scholefield D and Smith C. (2004) Grazing legumes in Europe: a review of their status, management benefits, research needs and future prospects. Grass and Forage Science, 59, 197-214.

[69] MIDAIR – Greenhouse Gas Mitigation for Organic and Conventional Dairy production, EC, Contract no: EVK2-CT-2000-0009t http://www.ie-leipzig.de/MIDAIR.htm

fertiliser and manures, with reductions of typically 30% under field conditions[70]. However the NZ grazing paddocks are generally free draining and have long growing seasons, whereas UK soils are predominantly heavy textured with a shorter growing season. The UK soils retain nitrate more in the clays, compared with free draining sandy soils over gravel. The principle of the technique has not been tested fully in the UK, although use in autumn applied slurries did not consistently reduce nitrate leaching.

- Consider switching to an organic system – Studies have shown different results with some concluding in favour of organic and others of conventional systems, the discrepancies are due to the complexities of balancing energy inputs and emission of methane and nitrous oxide[71] with crop yields/ha in both organic and conventional systems.

Table 5.3 Summary of quick wins and long term potential mitigation methods

Note - % figures and table format taken from the 'Review of research to identify best practice for reducing greenhouse gases from agriculture and land management. IGER. ADAS.2007'(unless otherwise stated), and adapted for Wales.

Mitigation measure examples	**Magnitude of source and target gas (kt CO_2 e)**	**Direct mitigative effects**				**Secondary & indirect effects**	
Potential quick wins		**N_20**	**Potential N_20 Reduction (kt $C0_2e$)**	**CH_4**	**$C0_2$**	**NH_3**	**$N0_3$**
Nutrient Management							
Not exceeding crop N requirements, – applying rates based on needs	**1615[a]**	**↓5%**	**↓80.75**	_	↓	**↓5%**	**↓5%**
Manure Management							
Make full allowance of manure N supply	**238[b]**	**↓5%**	**↓11.9**	_	↓	**↓5%**	**↓5%**
Spread slurry at appropriate times & conditions	**238[b]**	**↓2-10%**	**↓4.76 – 23.8**	↑	_	**↑10-20%**	**↓5-15%**
Ensure appropriate storage of manure and changing from a solid to a slurry based system	**417.6**	↓ ↓		**↓7%**[72] ↑			

[70] Dittert K, Bol R, King R, Chadwick D, Hatch D. Use of a novel nitrification inhibitor to reduce nitrous oxide emission from N-1 labelled dairy slurry injected nto soil. Rapid Communications in Mass Spectrometry 15, 1291-6, 2001

[71] Garnett.T. November. 2007. Exploring the livestock sector's contribution to the UK's greenhouse gas emissions and assessing what less greenhouse gas intensive systems of production and consumption might look like. Working paper produced a part of the work of the Food Climate Research Network. Centre for Environmental Strategy. University of Surrey

[72] A. Weiske et al. (2006), Mitigation of greenhouse gas emissions in European conventional and organic dairy farming, Agriculture, Ecosystems and Environment, Volume 112 (2-3):221-232

Long term potential actions						
Using the least emitting form of N fertiliser	**?**	↓				
Better mgmt of nitrogen flows	**?**	↓				
Use of nitrification inhibitors	**?**	↓	**-**	**-**	**-**	↓
Consider applying other fertiliser types e.g. green manure	**?**	↓				
Consider Anaerobic digestion practices		**?**	**↓90%**		**?**	**?**

[a] N_20 emissions from soils, i.e. inorganic fertilisers (FERT), manure spreading (FAW)and grazing (GRAZ)
[b] N_20 emissions from organic fertilser applications (FAW). This value includes both slurry and solid manure
↓ **-** reduction (positive effect)
↑ **-** increase (negative effect) **?** – unknown

NB- the potential reduction totals are based on total take up across Wales by all producers. In some cases the measure may not be suitable, therefore the potential should not be taken as the actual reduction achievable but a guide if all farmers did apply the measure.

5.4 Theoretical impact of the mitigation methods identified

A reduction in the use of N fertiliser on farms in Wales could give a reduction in GHG emissions. A 10% reduction in the use of Ammonium Nitrate on a 100ha, from 78kg N per ha to 70 kg N per ha, based on more effective use of fertilisers would reduce the emission from that farm as follows:

Direct N_20: 137kg to 124kg, converted to 4,030kg CO_2 e
Indirect N_20 from leaching: from 92kg to 82.5kg, converted to 2,945kg CO_2 e
$C0_2$: 210.6kg to 189kg = 21.6kg CO_2, off-farm from fertiliser production
The total reduction is 6,996.6 kg CO_2 e yr^{-1}.

Farm type scenarios are being produced for dairy farms, arable and livestock systems and figures from this section have been supplied to those authors. The potential for reducing on farm N_20 and $C0_2$ emissions following organic conversion is outlined below:

Organic systems: Conversion of farming practices to organic management could lead to significant reductions in N_20 and $C0_2$ emissions. Synthetic N fertiliser applications would be eliminated through conversion to organic practices (although on farm manure applications would be expected to increase with

consequent increase in emissions, to provide the required nutrients for crop growth).
The following emission reductions per farm conversion could potentially be expected, based on the probability that an upland farm would not apply the typical rate of N stated to each ha:

A typical Welsh upland organic farm's effective area, according to the organic farms survey data from the FBS survey 2004/2005 (Annex 2) is 136ha. It has already been stated that a typical farm applies 78kg N /ha from inorganic fertilisers**.** Based on 0.0176kg of N_2O emitted for each kg of N applied (1 - 0.1kg x 1.25% x44/28), 5.48kg of $C0_2$ e is emitted as a result of 1kg of N applied. On a farm basis, this would equate to a saving of **57.9t of CO_2 e per farm**.

However it is important to note that the emission factor for N_2O from applying organic manures can be higher than that for inorganic, if applied at inappropriate times and under adverse conditions. In addition, long term storage of liquid manures raises methane emissions, while N_2O emissions rise in solid manure systems. Although emissions per hectare tend to be lower in organic systems, emissions per unit output tend to be lower from conventional systems. It is important to note that emissions would not be zero if conventional producers switched to organic and green manures (see Section 7).

5.5 Evaluation of theoretical impact in relation to an evaluation of take up on previous WAG programmes.

As an indication, preliminary evaluation of the Catchment Sensitive Farming Scheme shows that 80% of farmers offered the option of nutrient management planning took up the opportunity. If the ADAS/IGER estimate of a 5% reduction in N_20 were to result from proper nutrient planning, this could give a reduction of 4% of N_20 emissions in Wales. This equates to 20 kt $C0_2$ equivalent from the direct application of fertilisers (this figure will be higher including the indirect emissions after leaching and run-off).

The potential emission reductions in relation to the primary measures identified can be considered in relation to the potential take up rate by landowners. Using the 80% take up rate stated within paragraph 6.1 above this would result in the following emission reductions for N_20:

Table 5. 4 (see table 5.3 for references)

Potential quick wins	Magnitude of source and target gas (kt CO2e)	At an 80% take up rate
Nutrient Management		

Do not exceed crop N requirements	**1615**	**5% reduction @ 80% take up =↓64.6**
Manure Management		
Make full allowance of manure N supply	**238**	**5% reduction @ 80% take up =↓9.52**
Spread slurry at appropriate times & conditions	**238**	**2-10% reduction @ 80% take up =↓3.80 – 19.04**
Ensure appropriate storage of manure and consider converting to a slurry based system (applicable to only a proportion of producers)	**417.6**	**?**

NB - the potential reduction totals are based on total take up across Wales by all producers. In some cases the measure may not be suitable, therefore the potential should not be taken as the actual reduction achievable but a guide if all farmers did apply the measure.

5.6 Future issues & Costs

A major driver for several agricultural sectors is continuing CAP reform and other Directives, considered in the DEFRA Baseline Forecast to 2025 (see Section 2).
It is hoped that most of the measures with the greatest potential could be taken up under "business as usual", or with little disruption to the day to day management.

Specific and detailed cost data could be obtained through an analysis of the Catchment Sensitive Farming (CSF) demonstration project costings data per farm. The CSF project provided individual farms with nutrient management advice to farmers. (e.g. soil sampling and RB209 calculations). Further internal research with Assembly colleagues could provide more detailed data to support this.

5.7 Data and knowledge gaps

The following paragraphs highlight areas where there is believed to be data/knowledge or research gaps:

Lack of Welsh data

There is a lack of information regarding welsh fertiliser and manure use/storage and application data. In order to develop and promote mitigation methods to reduce emissions it is essential to base assumptions on robust data. For example, the British Survey of Fertiliser Practice (BSFP) does include Wales only figures, but these are based on a very small sample of fields. Although Welsh figures were used for a breakdown of application rates for different farming systems, they were not robust enough to break down for different fertiliser types, or crop types. The BSFP could be extended onto a larger sample of welsh fields. Wales data could also be collected as part of the farm census format.

Manure research project life spans are too short

As confirmed by D Chadwick,[73] a number of research projects have and are currently being undertaken to ascertain the conversion of emissions from manure to GHG**.** It is thought that such surveys/project life spans are too short to provide reliable and robust data. There is also little data available on levels of emissions being converted to GHG under different management/ storage conditions. Problems exist particularly in measurements of N_2O

The current structure of the UK IPCC inventory does not give credit for management practice improvements

There is a need to develop smart emission factors to underpin the IPCC methodology; this could include variable rate mineral fertiliser N applications. IBERS is working on better process models which reflect management practices. These in turn will require more data collection for Wales.

Lack of data regarding differing soil types across Wales

Further research is required to quantify how changing slurry application timing would affect both direct and indirect N_20 emissions from heavy clay and highly organic soils. It has been highlighted by others that research to date focuses on sandy soils.

More research on legumes is needed

The nitrogen fixation and utilisation efficiency is still insufficiently understood with regard to legumes other than white clover.[74] The potential to use these crops to fix nitrogen biologically instead of chemical fixing needs further research in order to be exploited.

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[73] D Chadwick is co-author of – A Review of Research to Identify Best Practice for reducing Greenhouse gases from agriculture and land management. September 2007. DEFRA project AC0206 – IGER/ ADAS

[74] Garnett.T. November. 2007. Exploring the livestock sector's contribution to the UK's greenhouse gas emissions and assessing what less greenhouse gas intensive systems of production and consumption might look like. Working paper produced a part of the work of the Food Climate Research Network. Centre for Environmental Strategy. University of Surrey

6 Livestock farming (Dairy, Beef & Sheep)

6.1 Background to the livestock sector

6.1.1 Dairy

There are about 280,000 dairy cows in Wales within 3,368 dairy herds, which equates to an average herd size of 83 cows. There are approximately 2,300 Welsh milk producers and although this number declines at about 5.5% per annum, herd size and yield per cow are increasing, which keeps milk output relatively stable.

Economic forces coupled with improved technical performance have allowed total production to be maintained with lower cow numbers. This change has, as a by-product, reduced GHG emissions per litre of milk produced, and further change in this direction will continue to give further GHG reductions. Although this is a positive benefit, one disadvantage is the loss of beef production from the dairy herd. If milk and beef production are assessed together then the picture is less clear and it is probable that GHG emissions have increased. The higher yielding cow produces milk efficiently but with more extreme "dairy type" calves that are not suitable for beef production. This leads to beef production from suckler cows, a very inefficient system in terms of GHG production. If milk and beef were to be produced together in one system then a reduction in GHG overall would be achieved by keeping a lower milk yield "dual purpose" cow which also produces a beef calf.

6.1.2 Beef & Sheep

Wales plays an important role in production of store and breeding stock in the sheep and beef sector. Excluding the dairy herd, in 2005 there were 0.64million cattle and 8.61m sheep in the LFA and 0.22 m cattle and 0.9 m sheep in non-LFA[75].

Comment [Julie3]: can we go more up to date?

Beef Sector

Between 1995 and 2005 the beef cow population has continued to increase. The June 2006 census[1] showed a modest 1% further increase in the beef breeding herd.

[75] Welsh Agricultural Statistics 2006

Table 6.1 - Beef Industry Details

	1995	2003	2004	2005
Beef Cows ('000)	170.8	212.9	216.8	220.7
Number of holdings with Beef cows	9,276	8,684	8,565	8,502
Average size of Beef Herd	18	25	25	26
Average market price for Beef p/kg/lwt	123	96	103	97

The future is likely to see a consolidation in breeding cow numbers but a fall in the number of holdings keeping beef cows. Environmental regulation and the need for capital reinvestment in buildings and manure storage facilities will see fewer herds but carrying more cows. This trend is being replicated in the dairy industry.
Reductions in the actual number of breeding cows (Dairy and Beef) in Wales are also likely as we move to 2020. Presently the total herd stands at approximately 475,000 cows with a fall to 340,00 by 2020 estimated by HCC.

Sheep Sector

The Welsh ewe breeding flock has fallen from 5.5 million in 1995 to 4.7 million in 2005. The total number of sheep and lambs fell 2% between June 2005 and June 2006. The current total number of sheep and lambs is just over 9.3 million; while breeding ewes fell a further 1% for the same period.

Table 6.2 - Sheep Industry Details

	1995	2003	2004	2005
Total Sheep and lambs ('000)	11,100	9,859	9,736	9,510
Number of holdings	16,589	15,666	15,483	15,307
Average flock size (ewes and lambs)	669	629	629	621
Total breeding flock ('000)	5,501	5,016	4,957	4,732

In 2005, 15307 holdings in Wales kept sheep and breeding sheep were found on 14612 holdings – the average flock size of breeding ewes and rams is 316.
Wales still has a stratified sheep system made up of mountain / hill, upland and lowland. The flock size and structure is diverse. Hill ewe breeds dominate in Wales, in 2005 59% of ewes were hill, 22% upland and 20% lowland.

The larger flocks are getting bigger at the expense of the medium sized flocks. It is likely that ewe numbers will continue to fall in Wales but we will see a shift from smaller ewes to larger more productive crossbred ewes.

Based on current trends in the sheep industry in Wales, HCC has forecast that the sheep industry in 2020 could look as follows:

Table 6.3 – Forecast sheep numbers to 2020 (HCC)

	2005	2006	2010	2015	2020
Breeding Ewes (millions)	4.6	4.4	3.9	4.0	3.8
Lambs slaughtered (millions)	4.5	4.1	3.6	3.6	3.4
Cull ewes slaughtered (millions)	0.6	0.5	0.4	0.4	0.4
Total Production '000 tonnes	92	85	78	80	79

To maintain 2020 production levels at 2005 rates both lambing percentages and carcase weights would have to improve.

These trends are important for estimating the future 'business-as-usual greenhouse gas emissions, as the basis for further mitigation measures.

6.2 Key Emissions

The main GHG produced by livestock systems is methane from enteric fermentation, followed by nitrous oxide from manures and slurry. A small amount of carbon dioxide can be attributed to energy use on farm, from farm machinery, electricity use, water heating and milk cooling. This is addressed more fully in Section 9 (Bio-energy).

If artificial fertiliser is included then this adds significant emissions of carbon dioxide (although the manufacture of this is not included in the inventory under agriculture) and nitrous oxide. (Note that this has the single largest effect when conventional and organic farming systems are compared.) These emissions are addressed in Sections 5 and 8. This chapter will focus on methane emissions from livestock.

Table 6.4 - Summary of 2005 Agricultural CH4 and N2O Emissions by sector in Mt CO_2 equivalent (UK[76])

Comment [Julie4]: Wales or UK figures?

	CH_4	N_2O	Total
Dairy	5.6	4.4	10
Beef	8.2	6.0	14.2
Sheep	3.6	4.4	7.9
Pigs	0.4	1.4	1.8
Poultry	0.3	1.8	2
Arable	-	7.9	7.9
Total	**18.1**	**25.8**	**43.9**

Table 6.5 – Relative % significance of GHG's for the beef & sheep sector – Cranfield study IS0205

	CO_2	CH_4	N_2O
Beef	21	49	31
Beef – Organic	14	65	21
Sheep	19	50	31
Sheep - Organic	12	63	26

Foster et al[77] estimated GHG emissions to be:

- Sheep meat – 17.4 kg CO_2 equivalent/kg product
- Beef – 13.0 kg CO_2 equivalent/kg product
- Pig - 6.35 kg CO_2 equivalent/kg product
- Poultry – 4.57 kg CO_2 equivalent/kg product
- Milk – 1.32 kg CO_2 equivalent/kg product

From modelling of conventional dairy systems undertaken by Kite, about:

- 50% of GHG emissions comes from methane, enteric fermentation and manures,
- 25% from nitrous oxide via microbial breakdown of nitrate in soil,
- 25% from carbon dioxide from direct inputs, e.g. energy, chemicals, fertiliser, buildings, machinery. Some studies indicate that the emissions from production of forage and feed can be 35%, but much depends on the proportion of concentrate and grain in the diet.

The modelling also considered organic milk production and there are significant differences. As no synthetic fertilisers are used, carbon dioxide emissions from manufacture and nitrous oxide emissions following their use do not have to be

[76] UK GHGI and NERA / ADAS / OGER calculations
[77] C Foster, K Green, M Bleda, P Dewick et al. Environmental impacts of food production and consumption. DEFRA Report 2006

included. In organic systems, methane, when expressed per litre output becomes more important.
In all systems, conventional or organic, high or low yield, the most significant impact on GHG emission per unit output is technical efficiency.

Table 6.6 – GHG emissions/litre conventional, organic & hi-tech herds

System		GHG CO2 equivalent /litre milk
Average conventional	7500 litre/c, fertiliser 215kg/ha	875
Upper quartile conventional	8765 litre/c, fertiliser 192kg/ha	761
Average organic	5500 litre/c	781
Upper quartile organic	7000 litre/c	666

(Kite Consulting)

In the literature review undertaken by Garnett[78] [pages 54-55], five sources have calculated GHG emissions of between 640-1510 g CO_2 equivalent / litre milk. The calculations involved are not consistent and the researchers were comparing different dairy systems. This would explain the relatively large range. Generally, organic systems were found to have higher GHG emissions per litre due to the methane output being allocated to fewer litres. This is challenged by the organic farming movement, as there is no consistent approach to inputs of artificial fertiliser or purchased feeds. Although soil organic carbon levels tend to be higher in organic systems, from the inventory viewpoint, this is not an **additional amount of sequestration of carbon compared with conventional systems, unless the organic system imports material diverted from landfill.**

Methane from enteric fermentation
Methane is mainly produced in the rumen by methanogenic bacteria and is lost by eructation (belching) during rumination (chewing the cud). Plants fix the carbon in ruminant diets from atmospheric CO_2, therefore the process is effectively “carbon neutral” . The issue, however, is that the process of ruminant digestion converts some of the plant carbon to methane, which is 22 times more damaging as a GHG than carbon dioxide. Methane from enteric fermentation in cattle amounts to approximately 60% of total methane emissions from the agricultural sector, with enteric fermentation in sheep accounting for a further 36%. Methane emissions are largely dependant on livestock numbers, which have decreased in recent years, particularly in the Welsh sheep flock. The amount of methane is generated per quantity of output (meat or milk) will vary according to diet – both the feed stuffs and the digestibility of the pasture – and the way the manure is managed.

[78] Garnett.T. November. 2007. MEAT AND DAIRY PRODUCTION & CONSUMPTION. Exploring the livestock sector’s contribution to the UK’s greenhouse gas emissions and assessing what less greenhouse gas intensive systems of production and consumption might look like. Working paper produced a part of the work of the Food Climate Research Network. Centre for Environmental Strategy. University of Surrey.

Table 6.7 - Wales agricultural methane emissions (kt gas yr^{-1}) [79]

Livestock source	Enteric fermentation	Manure management	Total
Cattle	71	11	82
Sheep	48	1	49
Others	1	1	2
Total	120	13	133

Table 6.8 - Methane produced by enteric fermentation and manure management (kg methane perr head per year)[42]

	Enteric fermentation	Manure management
Beef animal	48	6
Sheep	8	0.2
Lamb< 1 year	3.2	0.1

Ruminant animals such as cattle, sheep and goats are able to digest a fibrous diet as a result of their digestive tract having evolved to a four compartment stomach. Certain other animals, for example horses, rabbits and to some extent, pigs and poultry are also able to digest fibre, but their digestive physiology is different. Non-ruminant mammals do produce some methane as a result of the digestive process but at a far lower rate.
Ruminants are unable to digest their feed entirely, particularly cellulose based plant polymers, by the action of the stomach enzymes alone. Instead, in the ruminant gut feed is broken down by bacteria and ferments prior to gastric digestion. Swallowed food enters the rumen, the largest of the four stomachs, which contains a large volume of liquid with a large and diverse microbial population. It remains there for a considerable amount of time where it is anaerobically fermented to form volatile fatty acids, ammonia, carbon dioxide, methane, cell material and heat. The volatile fatty acids are absorbed via the rumen wall and are available for metabolism by the animal. (A cow may derive up to 70% of its energy requirement from VFAs absorbed from the rumen).
The balance of these products varies between animals and with dietary intake, being largely determined by the composition and activity rates of micro-organisms present in the rumen. The gaseous fraction, methane and carbon dioxide, are waste products from the fermentation, cannot be used by the animal and are lost by eructation (burping). Methane loss accounts for an average of 6% (range 2 – 15%) of the available energy fed to the animal.

The next stomach, the reticulum, is effectively a compartment of the rumen. It accepts undigested fibrous material, which is formed into lumps (or cuds), which are regurgitated and chewed further to reduce particle size. Microbial cells and

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[7979] *based on NAEI data 2004*

food not degraded within the reticulo-rumen passes down to the omasum, which absorbs much of the water, then to the abomasum for further digestion. The abomasum is similar to the stomach of pigs or humans (sometimes called the "true stomach") and is the site of acidic and enzymatic digestion. Breakdown products from this further digestion are absorbed in the small and large intestine; these provide the remainder of the energy requirement and also protein and other nutrients.

The rumen therefore allows ruminant animals to utilise fibrous diets to produce dairy, meat and other products from feeds, which cannot be utilised by man or other animals. But, methane is an unavoidable by-product of the microbial fermentation conducted within the rumen. **The following approaches are considered to reduce the amount methane ruminants produce from enteric fermentation:**

- **Increased technical efficiency through management practices**
- **Reducing enteric fermentations by:**
  - Feeding diets that result in lower levels of methane
  - Modification of rumen fermentation by feeding additives.
  - Plant breeding for reduced GHG emissions

6.3 Opportunities to mitigate emissions using technical efficiency

6.3.1 Increased technical efficiency - Dairy

The lifetime efficiency of a cow depends on age at first calving, the number of lactations, calving interval, duration of dry period and lactation yield. All these factors determine the lifetime milk yield but GHG emissions remain relatively constant. Improving lifetime efficiency therefore reduces GHG emissions per litre.

- **Lactation yield**, methane is not greatly influenced by yield i.e. the more milk produced per cow = less methane per litre. Higher yields are generally achieved by higher inputs of concentrate feeds, the higher starch/sugar level and fine particle size of these feeds replace the high fibre forage feeds associated with higher methane output. However, pushing milk yields too high can have a detrimental effect on herd health and fertility and work against lifetime efficiency.
- An **improvement in cow longevity** has the greatest effect on lifetime efficiency, or output. Currently the average number of lactation's per cow is 3.44 (cf 4.76 thirty years ago) this has occurred because selection for milk yield traits has selected against those traits associated with fertility. There is also a link with herd health, with higher yielding cows more likely to be culled for foot problems or mastitis.

- **Improve dairy cow fertility** through genetic selection or nutrition, while maintaining yield. This can decrease the replacement rate.
- **Calving heifers at 2.0 instead of 2.5 or 3 years** will reduce lifetime emissions and recoup the investment in faster growth and development.
- **Increase use of sexed semen** could be an option to obtain the required replacement rate for the herd. This would enable only the cows of highest genetic merit to breed replacements and avoid having to produce pure-bred male calves which are not wanted for beef production. Pure dairy bred calves are less ‘efficient’ animals to finish as beef, their genetic make up having been selected for milk production. Sexed semen would allow those dairy cows not needed to breed replacements to produce male calves from beef sires. Alternatively, the breed make up of the Welsh dairy herd could be changed to breeds which are a ess extreme dairy type, such as British Friesian, Ayrshire, Dairy Shorthorn, MRI. Such breeds yield less milk but produce calves that can finish as beef animals. If the current trend in dairy cow breeding continues such that pure dairy-bred male calves are not used for beef, and if beef consumption is maintained, then the logical conclusion is that beef from suckler cows would have to increase. The beef suckler system of beef production is not as efficient in terms of GHG emissions compared with calves from dairy cows that are effectively a by-product of milk production.
- **Improved animal output by use of hormones**. This science is well established but currently banned within the EU. For example, recombinant bovine somatotropin (rBST) a synthetic version of natural growth hormone to increase milk output. Treatment with rBST is widely used in USA and often linked with three times a day milking. There are animal welfare implications to using rBST leading to a reduction in cow longevity.

Manure, slurry and soil
This is covered in more detail in other sections. However, changes to dairy cow feeding and management can reduce nitrogen output. Limiting protein (nitrogen) in the diet to the animal requirement can reduce nitrogen in waste. The cost of protein feeds has not been significantly higher relative to energy feeds and this can lead to rations being formulated which are much higher in protein than can be utilised. For example, dairy concentrate fed at grass is commonly 18% protein. As grazed grass is high in protein, possibly higher than 30%, then much of the dietary nitrogen is not used for production. Producing a concentrate with say 12-14% protein would require a high inclusion of cereal grain, costing more than imported by-products with higher protein content.

6.3.2 Increased technical efficiency – Beef & Sheep

The potential to reduce the GHG emissions from livestock using various methods of technical efficiency, (many of which have the added benefit of being cost-efficient to the farmer) mainly effects a reduction in livestock numbers in total by producing better yield (meat or fertility):

- **Increasing meat yield** from an animal over the same lifetime or attaining the same yield in a shorter lifetime – using optimum technical management to increase growth rates / output. For example work in Scotland has shown that reduction in finishing time for beef production saves significant emissions.
- **Selecting for higher fertility** – increased fertile longevity of ewes/sucklers, higher lambing percentages resulting in fewer replacement beef cows or ewes needed, reducing livestock numbers in total.
- **Selective breeding for efficiency**. Animals can be selected on the basis of digestive efficiency, productivity, resistance to disease.
- **Use of cloned animals** – use cloning techniques to increase the number of animals with desirable characteristics e.g. low residual feed intake / low CH_4 emission animals. Although this may offer more rapid progress public acceptance of this method is unlikely.
- **Improved animal output by use of hormones** This science is well established but currently banned within the EU. In beef animals, hormonal implants which include naturally occurring hormones (e.g. oestradiol 17β, testosterone, progesterone) or artificial analogues (e.g. trenbolone, zeranol) can increase growth rate by improved feed efficiency. Again these hormones are widely used in other countries, USA, Australia and New Zealand.
- **Genetic Manipulation** (GM) of Livestock – create livestock with lower GHG emissions. Again public resistance is likely.

Livestock breeding has concentrated in recent years on production traits rather than on animal health and robustness characteristics. Hybu Cig Cymru (HCC) are currently involved with around 10 sheep group breeding schemes, which are looking at improvements in terms of maternal and production Estimate Breed Values (EBV's). These groups provide an opportunity to factor in new criteria. The use of AI and ET in sheep and beef work will speed up the rate of genetic improvement.

6.4 Opportunities to mitigate emissions from enteric fermentation

The following approaches are considered to reduce the amount methane ruminants produce from enteric fermentation:

- Feeding diets that result in lower levels of methane
- Modification of rumen fermentation by feeding additives.
- Plant breeding for reduced GHG emissions

The simplest method, and a process which has been continuously developing, is to match animal diets closely to nutritional need. A more radical approach would be to change livestock management and feeding systems, for example to keep animals more intensively and feed concentrates. This approach has possible climate change advantages, but there are other issues of impacts on landscape (undergrazing, land abandonment), animal welfare and rural economy. In addition it is important to recognise the emissions associated with grain and concentrate production.

6.4.1 Feeding feeds with lower potential methane production

Identify methane emissions from diet. In the past feeds have been characterised in terms of their nutritional value but not for potential methane production. It would be possible to estimate potential methane production from a diet before it is fed and then to formulate the diets to keep methane production low. This approach would require some research to calibrate *in vivo* methane measurement against an *in vitro* measurement such as Near InfraRed Spectroscopy (NIRS). The techniques required are established and the research needed relatively inexpensive. However, if feeds were so characterised, there would need to be some economic driver to encourage low methane diet formulation.

Increase concentrate feeding: raise concentrate to forage ratio from 40:60 to 60:40. Effectively supplying less energy as forage and more as concentrates reduces methane production as a result of lower hydrogen production. Higher grain levels in the diet will decrease production of acetic acid and methane, however this may have a detrimental effect on cow health and welfare e.g. laminitis. Feeding of pelleted or ground forage or even reducing chop length of silage will also reduce CH_4. Forages containing starch, maize and arable silage, will also reduce methane emissions compared to grass silage.

6.4.2 Feeding to animal requirement

During the 1970s and 1980s there was much government funded research which increased the understanding of animal nutritional requirements. The “metabolisable energy system” (ME system) and then “metabolisable protein” (MP system) were developed and are now widely used to ration ruminant livestock. These systems evaluate the nutritional requirements for a given group of animals at a defined level of output, accounting for animal liveweight, liveweight gain/loss, milk yield, pregnancy and wool growth. From the known composition of feedstuffs, diets to meet animal requirements can be calculated so that an optimum balance between forage and supplement(s) can be reached.
For example feeding maize silage instead of grass silage to beef cattle reduces ruminant methane emissions by a potential 5% (and even though better soils & warmer temperatures are needed, this may well happen as a result of the effects of climate change). There may, however, be a GHG trade off in that growing maize may reduce CH4 but increase NO2 and CO2 emissions.
For the ME/MP systems to be applied successfully, farm grown feeds need some analysis and calculating rations in order to balance the diet requires the services

of an animal nutritionist. The calculations are complex and computer based, and the optimum result is steered by knowledge of the availability and composition of concentrate supplements. This process is commonly undertaken on dairy farms in preparation for winter feeding, but is relatively rare on beef and sheep farms. This is simply a reflection of feed costs relative to production in dairy systems.

More accurate feeding of ruminants could reduce methane emission per unit output but could also lead to more efficient use of dietary nitrogen. Much of the protein used by the animal is from digestion of microbial protein built up from the ammonia in the rumen. In order to capture this ammonia, rumen microbial growth should be maximised by providing sufficient fermentable carbohydrate. If the ratio of fermentable carbohydrate and ammonia is not optimum then either methane or ammonia will be lost from the rumen. Any ammonia excess not captured is absorbed into the blood stream and excreted by the animal. This in turn is linked to N_2O production in manure and slurry. Feeding a diet balanced in energy and protein will increase the efficiency of nitrogen use. Reducing crude protein concentration of the diet of a dairy cow, for example from 17.5 to 12.5% reduces N_2O excreted by 78%, however, this will reduce milk yield. Feeding for high yields also requires protein sources which are less degraded in the rumen and this will also decrease N excretion.

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6.4.3 Modification of rumen fermentation

Various feed additives can modify the rumen fermentation, by reducing the growth of methanogenic bacteria. These additives, antibiotic ionophores, were used in the past but are now banned within the EU (Reg 1831/2003/EC), the most commonly used was monensin sodium, (Romensin) which was incorporated into compound feeds or within mineral/vitamin supplements for on farm mixing. These products were developed and used as they increased animal output by more efficient use of the diet, a reduction in methane loss was a consequence and not a driver for their use.

Since these products were withdrawn there has been increasing interest in naturally occurring feed additives that could offer a similar effect. Various yeast products can change the microbial balance within the rumen. There are two types of yeast supplements available – usually referred to as 'live' or 'dead' yeast. The majority of yeast cultures on the market are live, e.g. Yea-Sacc, Levucell , and Biotal SC Gold. The main product that includes dead yeast is Diamond V XP. The mechanism by which yeast achieves the improved efficiency is not fully understood and is possbly due to a number of different effects. This also accounts for the variable response that would appear to depend on the diet fed, success is more likely with intensive diets.

Adding unsaturated fats in the diet (but not >5%) aids the digestibility of fibre, raises the energy density of the diet so allowing less grain based concentrates, such diets can be expensive. Other options being tested are the use of plant extracts containing tannins which may have a direct effect on rumen methanogens and an indirect effect on hydrogen production due to lower feed degradation

Some essential oils appear to be able to influence rumen microbial function, but this area of research is not yet developed. Recent studies show a reduction of methane generation by 14% *in vitro* by using sunflower oil or malic acid.

Another possible approach is to vaccinate ruminant animals against methanogenic microbes to reduce their influence within the rumen and thereby reduce methane production. Such immunisation has been demonstrated and reduced methane production in sheep by up to 8%. It is thought that the reduction occurred by delivery of antibodies in the saliva. The development of this technique could offer a significant reduction of methane emissions but further development work is needed to determine which organisms to immunise against, whether the rumen would adjust with other microbes undertaking methanogensis and the longer term effects on animal health. There are possible problems with public perception of vaccination against organisms that do not cause disease.

A current Defra R & D project (AC0209) is determining how the ruminant diet can be manipulated to reduce methane emissions and nitrogen excretion.

6.4.4 Plant breeding for reduced GHG emissions

Breeding forage, grass, legume new varieties which reduce enteric methane production is key to improving amino acid profile, reducing rumen protein degradation and improving fibre digestibility. The Institute of Grassland and Environmental Research (IGER) are currently carrying out plant breeding work on grass varieties bred to have high sugar levels. The altered diet changes the way that bacteria in the stomachs of the animals break down plant material into waste gas. There is also potential to breed plants which express nitrification inhibitors that reduce the nitrification of manure and mineral fertilisers to NH_4 and NO_3.

6.5 Scenarios showing impact on GHG emissions of suggested changes in livestock systems - short to medium term.

These scenarios have been based on typical farm types using data from the Farm Business Surveys (Annex 2) and assume that 6% of gross energy (GE) intake by livestock is lost as methane, calculated as 86.9 kg CH_4 yr^{-1} per livestock unit (Annexes 3 & 4).

6.5.1 Dairy

Reducing age at calving

Assume replacement rate for 119 cow herd is 30 heifers per year:

If rearing a replacement to calve at 2.5 years:

	No	months	Lus	Total Lus
Dairy youngstock 0 - 12 months	30	12	0.30	9.00
Dairy youngstock 12 - 24 months	30	12	0.54	16.20
Dairy youngstock 24 months +	30	6	0.80	12.00
Total LUs				37.2

Emissions would be 37.2* 86.9 kg CH_4 x 21(conversion coefficient to CO_2 e)
= **67.89 t CO_2 e yr^{-1}**

If rearing a replacement to calve at 2.0 years:

	No	months	Lus	Total Lus
Dairy youngstock 0 - 12 months	30	12	0.30	9.00
Dairy youngstock 12 - 24 months	30	12	0.54	16.20
Dairy youngstock 24 months +		6	0.80	0.00
Total LUs				25.2

Emissions would be 25.2* 86.9 kg CH_4 x 21(conversion coefficient)
= **45.99 t CO_2 e yr^{-1}**
Therefore rearing 30 replacements to calve at 2 years compared to 2.5 years saves 21.90 t CO_2 for this farm per year.

There would also be savings in other GHG emissions associated with the lower stocking rate.

Expanded across Wales' 2,300 milk producers, this shows a potential saving of 50.37 kt CO_2e yr^{-1}.

Increasing milk yield per cow
Milk yield per cow of 6519 litres (FBS data) = total herd milk output of 119 cows is 755,761 litres.
If this milk was produced by 100 cows yielding 7558 litres this would give the same herd yield, and reduce methane output by 19 cows. There would be an associated reduction in the number of replacements.

119 Cow herd	No	months	Lus	Total Lus
Dairy cow	119	12	1.00	119.00
Dairy youngstock 0 - 12 months	30	12	0.30	9.00
Dairy youngstock 12 - 24 months	30	12	0.54	16.20
Dairy youngstock 24 months +	30	6	0.80	12.00
Total lus				156.2

100 Cow herd	No	months	Lus	Total Lus
Dairy cow	100	12	1.00	100.00

Dairy youngstock 0 - 12 months	25	12	0.30	7.50
Dairy youngstock 12 - 24 months	25	12	0.54	13.50
Dairy youngstock 24 months +	25	6	0.80	10.00
Total lus				131

156.2 LUs – 131 LUs = 25.2
25.2 * 86.9kg CH_4 x 21(conversion coefficient) = **45.99 t CO_2 e saving for this farm per year.**

Expanded across the 2,300 milk producers in Wales, this shows a potential total saving of 105.78 kt CO_2e yr^{-1}.

6.5.2 Beef & sheep

To calculate a specific benefit to each of the potential technical improvements is difficult (a large amount of arbitrary assumptions would have to be made) – but collectively 'production efficiency' may reduce methane emissions by around 10% in Wales.[80] Many of the potential savings are inter-dependant – farmers will be able to make small improvements in several areas. Also, some producers will fail to make improvements for a variety of reasons while others may be able to gain significantly more than 10% reductions.

Reduce finishing period for beef cattle from 30 months to 24 months.
This would equate to a 20% reduction in methane emissions from a beef finishing system. Many Welsh beef farmers will have 'store' periods in the production cycle of Welsh beef. Most beef animals from the beef and dairy herds are capable of faster daily live weights than are currently being achieved. Reduction of age at slaughter from 30 months to 24 months would be equivalent to reducing methane emissions by 20% per cycle. It would be wrong to assume that all beef finished in Wales is 30 months at slaughter, but a considerable proportion would be in this age range. Improvement to management and nutrition techniques has considerable potential to reduce finishing periods and therefore methane emissions.

On the typical farm type example used (Annex 2) – the lowland beef and sheep farm has 86 other cattle – assume these are mainly finishing cattle:

86 cattle @ 0.6 GLU / head = 51.6 total GLU for finishing beef
51.6 * 86.9 kg CH_4 = 4484 kg CH4 (4.48 t CH_4)
4.48 * 21 = 94 t CO_2 equivalent

[80] Market Mechanism for Reducing GHG Emissions from Agriculture, Forestry and Land Management. Defra NERA Economic Consulting September 2007

94 t CO_2 @ 20% reduction

= 18.81 t CO_2 e yr^{-1} saving for the beef system

Reduction in replacement rate of the Welsh ewe flock

The Welsh ewe flock is currently 4.7million. The average replacement rate for ewes in most systems would be approximately 25%. Through a variety of nutritional, management and breeding techniques, ewe life could potentially be extended to reduce the number of replacements needed to 15%. If the replacement rate is 25% of 4.7m = 1.175 m replacements to be reared and retained annually. Reduction of the replacement rate to 15% means that 0.705m replacements are needed, a reduction of 470,000 head per year.

470000 @ 0.1 GLU per head = 47000 GLU reduction per year in the Welsh flock. (47000 GLU is 9% of the 525630 total sheep GLU in Wales [Annex 3]).

The resulting methane emissions from the total Welsh sheep flock:
525630 * 86.9 kg CH_4 = 45677 t CH_4 yr^{-1}

Equivalent to 45677 * 21 = 959 kt CO_2 yr^{-1}

Possible reduction through reduced replacement rate @ 9%
= 86.3 kt CO2 yr^{-1}

Improve Lambing % in the Wales national flock by 10%

From the 4.7 m ewes (2005) there is an average lambing percentage of 120% producing 5.64 m lambs in total per year. An improvement in lambing to 130% would mean that the 5.64 m lambs could be produced by 4.33 m ewes. This would provide a reduction in 370,000 ewes from the Welsh breeding ewe flock and a reduction in the numbers of replacements needed, therefore saving approximately 8 - 10% of the total sheep methane emissions in Wales.

Table 6.9 Potential emissions savings per year at 10% general technical efficiency rate for the example beef & sheep farms (t CO_2 e)

	Total glu 's	t CH_4	10% efficiency	t CO_2 e
Hill Farm	151	13.12	1.312	27.5
Lowland Farm	120	10.42	1.042	21.9
Organic	109	9.4	0.94	19.7

Total potential GHG reductions for Wales from technical efficiency:
(based on lu data 2005 (Annex)):

Total beef = 453638 lu x 86.9 kg CH_4 per lu = 39421 t CH_4 yr^{-1}
= 827 kt CO_2 e
10% efficiency = 82.7 kt CO_2 e yr^{-1}

Total sheep = 525630lu x 86.9 kg CH_4 per lu = 45677 t CH_4 yr^{-1}
= 950 kt CO_2 e
10% efficiency = 95 kt CO_2 e yr^{-1}

6.5.3 Enteric fermentation

Accurate feeding in the dairy sector may achieve1% of the 6% methane lost from GE intake (16.7% of emissions), particularly as this sector tends to be technologically advanced and open to efficiency savings. However, the beef & sheep sector has a much lower potential saving of around 5% of methane emitted; the industry is more extensive as a whole (the majority of farms being in the LFA) and is also more resistant to change. Table 10.2 (Section 10) applies this estimate to the example farms.

6.6 Knowledge gaps and constraints

- **Methane emissions from dairy cows** can only be estimated from the number of animals and methane output per animal. As dairy systems and diets are diverse, the estimate of methane from individual animals is unlikely to be accurate. Similarly, the nitrous oxide output from dairy systems is also variable, as there are many different practices slurry and waste management. Nitrous oxide emissions are poorly quantified, yet have significant effects on overall emissions.

- There has been a great deal of research on dairy cow feeding, breeding and management, nearly all focused on increased cow output but little research on the effects of dairy farming on climate change.

- **Reducing Livestock numbers:** Reducing livestock numbers is a contentious issue as the farming industry would see it as a loss of income.
  In Wales breeding ewe numbers are already reducing year on year by about 1 or 2%. From 1996 to 2006 the ewe flock in Wales fallen from 5.5 million to 4.7 million (15%). The reduction in ewe numbers is a reflection of low profitability in the sector and the introduction of the Single Payment Scheme (SPS) which does not require a certain number of ewes to be retained.
  Beef cow numbers in Wales have fluctuated over a similar period after recovery from the BSE crisis and export bans in1996 and during the foot & mouth outbreak in 2001.
  The number of holdings in Wales keeping sheep and cattle is generally declining, through consolidation into larger units at the expense of the medium sized units. About 46% of breeding sheep holdings account for 90% of the breeding sheep flock, in the beef sector 46% of the beef holdings account for 83% of the beef herd.

- Any drop in numbers must be matched by a corresponding drop in consumer demand for meat and animal products, otherwise methane emissions will merely be displaced to production in other countries. Although reduction of livestock would reduce Wales farming activity and therefore emissions, the imports then needed could in fact effect an increase in global emissions because of the additional emissions associated with the transportation of agricultural products back to Wales.

- The knowledge required to make informed decisions on climate change requires a systems approach, if this is undertaken on research sites then the work is very expensive. The alternatives are to model existing knowledge and predict the effects of various changes or to monitor commercial dairy farms with less control of variables.

  A great deal of basic science on rumen function and modification of rumen fermentation has been undertaken up until the mid 1980's. This was motivated by increased output and efficiency to make animal keeping more profitable. The loss of about 8% of feed energy as methane represents a significant loss to the animal and the farmer. The research at this time was focused on increasing livestock output or reducing the cost per unit output. There was no emphasis on reducing methane production in light of climate change. As highlighted above, there are various approaches to reducing rumen methane emissions which merit further research. Vaccination against methanogenic organisms and feeding plant extracts/essential oils appear to offer good potential for methane reduction.

- Reconciling key emissions with the GHGI has proved to be difficult. Ability to build up inventories from bottom up or top down would have been beneficial to the exercise. Some guidance from IGER and CEH would prove useful.

- Improvement in understanding of potential methane production of feeds and transfer of this knowledge to the farmer. Laboratory methods have already been developed to estimate potential CH4 production from a feed before it is fed.

6.7 Conclusions

- Methane from enteric fermentation represents the most important emission from dairy and livestock farming. It is an inevitable consequence of keeping stock but there are a number of changes to systems that would reduce methane output (Section 7). The easiest and most effective GHG mitigation option is to increase technical efficiency on dairy farms. Technical efficiency results in carbon efficiency. The knowledge to achieve this already exists, although further research is required to improve this further.

- The development of better nutritional strategies including diet quality, forage composition, and use of additives such as plant extracts, lipids, organic acids, and antimicrobial compounds is ongoing, but there are insufficient data to judge their effectiveness. The whole area of life cycle analysis lacks data. Some of the proposed measures are too costly or are insufficiently proven to be adopted at this stage.

- Reducing ruminant emissions in general is effected by reducing the number of ruminant animals kept. Unless the UK is to export the problem then this means that the population will have to accept a lower consumption of dairy products, beef and lamb. If there is a switch to meat from pigs and poultry then emissions from the production of these meats must be balanced against those from ruminants. No such switch can be made for dairy products. A return to the levels of animal products consumed in the 1950's would reduce emissions significantly, and give a healthier diet, possibly saving the planet and us.

- There is potential to reduce GHG emissions further by producing beef within the dairy system by keeping a dual purpose cow which produces a beef calf. Some breeds such as South Devons and Shorthorns are well-suited to this. However, it is likely that economic conditions would be the driver for this, say if:
  - value of dairy calves and/or dairy cull cows increase as suckler beef reduces and imports become more expensive
  - consumers reject dairy produce from the current system where day old calves are culled and/or cows last less than 3 lactations
  - concentrate feeds and/or fuel for forage conservation and/or vet and medicinal fees become prohibitively expensive

7 Cropping (Arable, Plant Breeding, Seeds, Pesticides, GMOs)

7.1 Key Emissions

The arable industry in Wales is relatively small compared to that of England and Scotland and occupies approx. 4% of Wales's total agricultural land use, some 64988ha[81]. Of this total arable area, 41515ha is put to cereals, 9099ha to forage maize, 2959ha to OSR and 2190ha to potatoes. The remaining 9225ha is used for other stockfeeding crops, horticulture, sugar beet, linseed and other alternative crops.

Arable cropping produces both CO_2 and Nitrous Oxide (N_2O). Carbon dioxide emissions from cropland in Wales were 1041 kt CO_2, in 2005, due mainly to conversion of grassland to cropland. There is a small carbon dioxide sink (11.1 kt CO_2) due to the annual increase in the biomass of cropland vegetation as a result of yield improvements. Liming also contributes a small amount of carbon dioxide – around 6 kt CO_2 equivalent. Other emissions come from energy inputs for cultivation and crop drying. Energy inputs for fertilisers and agri-chemicals are areas where agriculture has an influence, but actual emission are reported in the chemical sector. N_2O is the biggest emission source from all agricultural soils (2647 kt CO_2 equivalent), although the contribution from arable crops has not been estimated separately.

7.1.1 Carbon Dioxide

The majority of CO_2 produced from this sector is from fuel and energy (primarily electricity) use and from land use change from grassland to arable.

Fuel use

Around 36% of direct energy use in agriculture is gas oil and diesel for field operations. The largest users are the arable crop (66%) and livestock (31%) sectors. Savings in fuel use can be made by ensuring correct tractor ballasting, tyre selection, implement matching and reduced cultivations, but it is thought unlikely that these measures have the potential to save more than 10% of the total fuel consumed[82].

Biodiesel or straight vegetable oil (SVO) could be used as a substitute for conventional diesel with little or no capital cost implications. Conventional fuel is an expensive commodity and farmers are already looking for ways to reduce the amount used. It is unlikely therefore that there is much needless fuel wastage within the arable industry and therefore little scope for GHG savings in that context. Added to this, Biodiesel and SVO are currently considerably more

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[81] Figures are for 2005, Welsh Agricultural Statistics 2006.
[82] http://www2.warwick.ac.uk/fac/sci/whri/research/climatechange/cgenergy/

expensive than red diesel, rendering them still more unlikely to be taken up in preference.

Energy use
Very little electricity is used within the arable sector. Electricity for drying grain and refrigeration of potatoes are the only significant uses. While refrigeration is now largely unavoidable, the need for drying of grain may be reduced as a result of the predicted effects of climate change. As the temperature increases and summers become dryer, the crop potentially could be harvested at the correct moisture content for sale.

7.1.2 Nitrous Oxide

GHGI Figures for Wales (2005) show the sources of N_2O emissions of which arable production is a contributory factor to be:

1. Leaching of fertiliser nitrogen and applied animal manure to ground and surface water (29% of total emissions) = **767.9** kt CO_2 equivalent
2. Synthetic fertiliser application (19%) = **503** kt CO_2 equivalent
3. Manure used as fertiliser (9%) = **238.3** kt CO_2 equivalent
4. Ploughing in of crop residues (1%) = **26.48** kt CO_2 equivalent
5. Cultivation of legumes (<0.1%)[83]. = **2.648** kt CO_2 equivalent

NB: 1.,2.& 3. refer to emissions from manure & fertiliser use for all sectors.

No breakdown for the emissions for arable land exists. Large amounts of fertiliser are used to produce arable crops. As grain prices increase with demand, efficient use of fertiliser will be essential. Pretty et al[84] compared the GHG emissions from conventional versus organic production, which showed that significant savings can be created by switching to organic, however this did not take into account the reduced yield from organic compared to conventional systems. This is considered in Section 5. One other option would be to grow oats for stockfeed, a lower input crop more suitable for the Welsh climate. Current research by IBERS has resulted in improved fat and protein content of naked oat varieties and there is potential to extend this to husked varieties, which have higher yields.

N_2O is produced during the manufacture and application of synthetic fertilisers within the arable industry and is also emitted from crops. Table 7.1 gives an indication of the level of field losses from different crops. Certain crops emit more N_2O than others; (this figure does not include the amount of N_2O emitted through manufacturing the synthetic fertiliser).

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[83] Scoping the environment and social footprint of horticultural food production in Wales, University of Wales Bangor, CALU 2007.

[84] Pretty et al. 2005 - Farm Costs and food miles: An Assessment of the full cost of the UK weekly food basket -

Table 7.1. Estimated losses of N_2O from crops[85].

Crop	kg N_2O ha^{-1} $year^{-1}$
Potato	1.1-2.9
Sugar beet	0.5-2.0
Winter wheat	0.3-0.9
Oilseed rape (*Brassica* ssp.)	0.7-0.8
Spring barley	0.5-0.8
Pea (*Pisum* ssp.)	0.2

Studies have found that total emissions of N_2O from potatoes are 70 % more than from barley and more than four times greater than from winter wheat[86].

The total fertiliser usage within the arable area of Wales can be calculated by multiplying the average application figure taken from the British Fertiliser survey with the area of arable land in Wales (Section 5).

From the CLIO report methodology used In Table 5.1: for every kg of N applied, 5.48kg CO_2 is emitted, and the manufacturing process of nitrogen fertiliser creates an additional 3kg of CO_2 for every 1kg of N manufactured[87]. In total therefore, for every 1kg of N manufactured and applied 8.48kg of CO_2 e is emitted, with the emissions from manufacture being assigned to the chemical industry, and the emissions from application to agriculture. For Wales, based on 8708 tonnes (2006) of N applied to arable land, the total GHG emission is **47.72 kt CO_2e .**

7.2 Actions to Mitigate Emissions

Potential options considered for mitigating N_2O and CO_2 emissions from arable soils include[88]:

- optimising application of artificial nitrogen inputs
- use of winter cover crops/green manures
- breeding new varieties which require lower agrochemical inputs
- zero/minimum tillage

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[85] Tzilivakis, J., Jaggard, K., Lewis, K.A., May, M. & Warner, D.J. (2005) Environmental impact and economic assessment for UK sugar beet production systems. *Agriculture, Ecosystems and Environment* **107**, 341-358.

[86] Smith, K.A., Thomson, P.E., Clayton, H., McTaggart, I.P. & Conen, F. (1998) Effects of temperature, water content and nitrogen fertilisation on emissions of nitrous oxide by soils. *Atmospheric Environment* **32**, 3301-3309.

[87] Williams, AG; Audsley, E and Sandars, DL (2006), Determining the environmental burdens and resource use in production of agricultural and horticultural commodities. Main report, DEFRA research project IS0205. Bedford; Cranfield University and DEFRA.

[88] Sherlock, J. (2006) (ed.) Defra research in agriculture and environmental protection between 1990 and 2005. Summary and analysis (ESO127). Department of Environment, Food and Rural Affairs.

7.2.1 Optimising Artificial Nitrogen inputs

This has been discussed in Section 5. In many arable crops, nitrogen availability is the limiting factor; consequently the application of fertiliser is very cost effective. Nitrogen can also promote soil carbon gains (see Soils Section). The optimum level of Nitrogen to be applied will be dependent on the price expected to be received for the crop, however, it is important not to exceed the crop's requirement. Over-application increases the risk of nitrous oxide emissions, nitrate leaching and most importantly for the farmer, can actually decrease yield.

There are various methods that can be used by arable farmers to ensure that the crop's nitrogen requirement is not exceeded:

- Use of a recognised nutrient management planning system to ensure optimum rates of applications: e.g. PLANET[89] or RB209[90] and other supplementary guidance such as for precision farming or canopy management techniques to plan fertiliser applications to all crops[91].
- Timing fertiliser applications to minimise the risk of loss of N: e.g. avoiding autumn N applications and early spring timings to drained clay soils. This is not usually included in nutrient management planning programmes.
- Taking full account of manure inputs when planning mineral fertiliser applications. Ensuring manure is tested prior to application to inform the choice of synthetic fertiliser.
- Ensuring accurate use of synthetic fertilisers by good maintenance and accurate calibration of spreading machinery and the use of good quality fertilisers.
- Using a professional Fertiliser Adviser Certification and Training Scheme (FACTS) adviser or being FACTS qualified themselves.
- Using a nitrogen sensor system such to allow targeted nitrogen application within the field.
- Using a winter cover crop or green manures (see below).

Fertiliser should be applied so that it coincides with crop requirements in order to minimise leaching, which leads to increased diffuse pollution and emissions of N_2O. Ensuring that all applications are carried out under good weather and soil conditions is important for the same reasons. Leached N is wasted N, both fromthe point of view of cost benefit to the farmer and the cost to carbon

[89] Planning Land Applications of Nutrients for Efficiency and the Environment; www.planet4farmers.co.uk

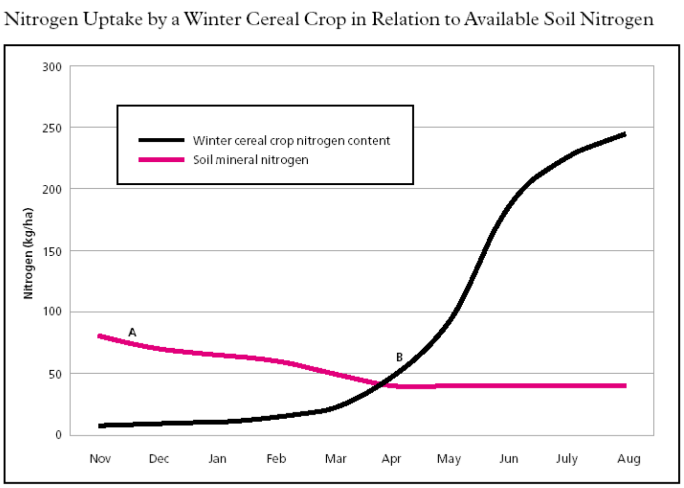
[90] *Fertiliser recommendations for agricultural and horticultural crops (RB209): Seventh edition (2000). http://www.defra.gov.uk/farm/environment/land-manage/nutrient/fert/rb209/index.htm*

[91] A review of research to identify best practice for reducing greenhouse gases from agriculture and land management – IGER, ADAS 2007.

emissions. Timings should be planned in conjunction with nutrient management planning.

Many arable farmers falsely believe that an N application is necessary in the autumn for winter cereals, but this is not the case. Crop N requirement is low in the autumn and winter and can easily be met by Soil Mineral Nitrogen (SMN), thus negating the need for autumn applied fertiliser for autumn sown cereals[92].

Table 7.2 – Comparison of crop uptake with SMN availability



As table 7.2 illustrates, the main period of N uptake is March-June. During this growth period there is usually insufficient SMN to support unrestricted growth. N should be applied at the start of and during the period. Early spring Nitrogen will increase tillering. While this may be beneficial in increasing crop yield, it is also likely to increase the risk of lodging.

7.2.2 Use of winter cover crops/green manures

Winter cover crops are grown as a grazing crop throughout the winter. Examples are stubble turnips or other brassicas. The crop is grazed and then what is left is incorporated back into the soil, increasing the N levels within the soil for the future crop.
Green manures are crops grown with the specific intention to be incorporated back into the soil, providing nutrients for future crops. Green manure crops include lucerne, clover etc. These crops require a zero N application.
Whilst winter cover crops and green manures are often used as integral to organic systems, they are not suitable for all arable systems and require a shift to spring cereal production, which will have an impact on yield. However it is predicted that

[92] Fertiliser Recommendations for Agricultural and horticultural crops RB209 (2000)

the effects on temperature and rainfall of climate change will increase the potential yields of spring cereals and other spring crops.[93]

7.2.3 New Varieties

Breeding provides opportunities to reduce emissions through genetic improvements for new varieties with characteristics which mitigate climate change. But varieties can take 10-12 years typically, from creation to being accepted for the National List (NL). To date there have not been any varieties presented for NL approval with specific climate change mitigation or adaptation characteristics but it is likely that plant breeders are already working on varieties with these characteristics.

The Forum on Seeds for a Sustainable Environment (FOSSE) was established in 2001 and has outlined their proposals in response to climate change[94].

Table 7.3 – Suggested characteristics for sustainability of new varieties and their mitigations of the impacts on climate change

Mitigation Characteristics	Some of the benefits to mitigation of climate change
Early Vigour	Allows the crop to establish quickly, reducing competition from weeds and need for herbicides (CO_2).
Adaptation to later sowing	Greater flexibility of sowing allows weeds to be removed by cultivation prior to sowing (CO_2).
Plant competitive ability	The ability to out-compete weeds for light, water & nutrients; less need for fertiliser or herbicides (N2O & CO_2).
Fungal resistance	Reduce the need for fungicides (CO_2).
Pest resistance	Reduce the need for pesticides (CO_2).
10% increase in yield	Help combat decreasing arable land available against an increasing world population, less need for fertiliser (CO_2 and N2O)
Total aerial mass	The ability to smother weeds, reducing herbicide application (CO_2).
Straw stiffness	Strong straw prevents lodging (CO_2).
Sprouting and spreading resistance	Reduces the waste within the crop both pre and post harvesting
Reduced N requirement	Reduce the need for artificial fertiliser (CO_2 and N2O).
Better efficiency of N	Crop is able to utilise more of the available N (N2O).
Uniform maturity	Shortens the harvesting window, allows more effective uptake of targeted inputs (N2O).
Drought resistance	Reduce irrigation needs and allows crops to be grown in more arid areas.

[93] Environmental and distributional impacts of climate change in Scotland
ESRC / Hanley (2004) Ref:R000239787
[94] http://www.defra.gov.uk/planth/pvs/FOSSE/fosse02.pdf

7.2.4 Zero/minimum tillage

Zero tillage (known as direct drilling), is based on use of a seed drill which cuts through the existing stubble with no cultivation, soil movement or consolidation. It is best suited to existing arable systems on stable soils with a good crop rotation, minimal crop residue and minimal amount of grass weeds. However, herbicide and insecticide usage often increases under this system due to the competition from weeds.

Minimum tillage shakes/cuts up the top layer of soil to a depth of approx. 6cm using a series of discs with a drill, reducing energy input and associated CO_2 emissions by decreasing the number of cultivation passes needed to create a seedbed down to a single pass. It allows a more natural soil structure to build up over time with organic matter being incorporated by worms and soil organisms. Minimum tillage can be undertaken on most soils using the appropriate machinery and soil management. It is ideally suited to well structured stable soils i.e. clays; on less well-structured soils such as sands and silts additional care/management is required. Again additional herbicide and insecticide use is necessary to manage weeds.

While conventional cultivation methods bury the existing crop residues, under zero or minimum tillage techniques these residues are largely retained on the surface as are the pests and diseases that infect the crop. While zero or minimum tillage can reduce the cultivations to a single pass, there are also 'lesser' passes needed to spray pest- and herbicides. Careful pest and disease management is essential if any fuel savings are to be achieved.

Smith et al[95] have concluded that zero/minimal tillage has the mitigation potential of 0.53 t CO_2 e ha^{-1} yr^{-1} (range is 1.12 to -0.04) for cool-moist climates. However, Bhogal et al.[96] concluded that any CO_2 saving would be completely offset by the increased N_2O emissions due to an increase in topsoil wetness and reduced aeration as a result of less soil disturbance. In addition, if the land is subsequently rotationally ploughed every few years, the increased soil carbon will be lost.

[95] P Smith et Phil Trans R Soc B 2007 Greenhouse Gas mitigation in agriculture

[96] Bhogal et al. 2007 The effects of reduced tillage practices and organic material additions on the carbon content of arable soils. DEFRA research project SP0561.

7.3 Scenarios showing impact on GHG emissions of mitigations identified

Example Farm used for Scenarios[97]

Table 7.4 - Typical 200ha arable farm comprising of crops as follows:

Crop	**Ha**	**Optimum N requirement per ha of crop (kg)**[98]	**Optimum N required on example farm (t)**[99]	**Typical N applied per ha of crop(kg)**[100]	**Typical N applied on example farm (t)**[101]
Winter Wheat	80	250	20	197	15.76
Barley: Winter	30	160	4.8	141	4.23
Spring	10	125	1.25	111	1.11
Potatoes: Early	5	130	0.65	158	0.79
Main	25	160	4	158	3.95
Forage Maize	10	60	0.6	67	0.67
Other stockfeed; swede, turnip	10	50	0.5	53	0.53
OSR	40	250	10	196	7.84
Total N			**41.8**		**34.88**

With a Wheat - Wheat - Barley – OSR – Potatoes/Maize rotation
Swedes and turnips are grown in the same year and on the same ground as potatoes as a winter cover crop.
Overall N requirement for the farm = 41.8t, likely to be applied = 34.88t

7.3.1 Scenario 1 - Nitrogen Sensor

The Nitrogen Sensor works by determining the crop's Nitrogen requirement and applying the correct fertiliser rate. The sensor measures light reflectance from the crop, and controls the sluice gate on the fertiliser hoppers of the fertiliser spreader. The N sensor works by measuring light reflectance from the crop from four different angles, with a fifth sensor positioned skywards measuring the intensity of light to allow the sensor system to compensate for different light conditions while operating. The whole process of determining the crop's Nitrogen requirement and application of the correct fertiliser rate happens instantaneously, with no time delay. This enables 'real time agronomy' to be possible.

This type of system is estimated to save approx. 5% of Nitrogen, thus reducing the amount of N applied and wasted. This translates to a 5% reduction in synthetic

[97] Farm Business Survey data
[98] The Agricultural Notebook – Primrose McConnell (1986)
[99] The Agricultural Notebook – Primrose McConnell (1986)
[100] British Survey of Fertiliser Practice 2006
[101] British Survey of Fertiliser Practice 2006

fertiliser manufacture and application emissions and a potentially higher reduction in the amount of N_2O emitted from leaching sources.

Using the typical 200ha Arable farm example (Table 7.4) growing Cereals, Potatoes and OSR):

The overall N requirement for the farm is 41.8t N, and on the basis that using a Nitrogen Sensor a reduction of 5% of N used can be achieved, this equates to 2.09t N saved per year, an emissions saving of 2.09t x 8.48 = **17.72t CO_2 equivalent**.

However, the typical application for the farm is more likely to be 34.88t, reducing the saving to 1.74t N, or **14.75 t CO_2 equivalent.**

It is possible to apply this to all Wales, using application figures for the different crops from the British Fertiliser survey.[102] These figures are 'typical' amounts of fertiliser applied, rather than the optimum that the crop requires.

Table 7.5 Total ha of arable crops in Wales (2005)[103] and typical N applied

Crop	**Ha Grown**	**Typical N applied on crops in Wales (kg/ha)**	**N applied to whole crop in Wales (tonnes)**
Winter Wheat	14812	197	2918.0
Barley: Winter	7570	141	1067.4
Spring	14196	111	1575.8
Oats	2930	122	357.5
Mixed Corn; Rye, triticale	2007	107	214.7
Potatoes: Early	841	158	132.9
Main	1349	158	213.1
OSR	2959	196	580.0
Total N			**7059.3**

Total N required = 7059.3 tonnes.
The Nitrogen Sensor could save 5%, or **353t N yr^{-1}**, which equates to **2.993 kt yr^{-1} of CO_2 equivalent.**

7.3.2 Red Clover Cover crop

If a change to the rotation were made to incorporate a green manure such as a Red Clover/Ryegrass ley, this would increase the soil mineral nitrogen (SMN)

[102] British survey of fertiliser practice 2006
[103] Welsh Agricultural Statistics 2006

levels and reduce the requirement for artificial fertiliser for the next cereal crop. The new rotation would consist of:

Red Clover/Ryegrass ley
Winter Wheat
Winter Barley
OSR
Winter Wheat/Stubble Turnips
Early crop Potatoes/Mustard
Winter Wheat

This system will require more livestock than previous rotations, in order to make the Grass/Clover ley cost efficient. To avoid capital investment in livestock equipment and buildings, one option is to purchase store lambs for grazing the ley after a cut of silage has been taken. The lambs could also graze the stubble turnips.

Grazing store lambs on the red clover/ryegrass ley will produce methane. However, less methane will be produced from grazing stubble turnips than from a more fibrous diet such as grass/silage (see Ruminant Emissions section).

A red clover/ryegrass ley is sown in August, with no fertiliser applied. A cut of silage is taken in May. Lambs are allowed restricted grazing after suitable regrowth. Lambs are removed 4 weeks prior to ploughing in. At this stage it is estimated that the incorporation of the red clover/ryegrass ley will return 150 kgNha^{-1} [104]. This will therefore reduce the future crop requirement for in this case winter wheat by 150 kgN ha^{-1}, resulting in only a top dressing being required in the spring of approx. 100 kgN ha^{-1} to bring the application up to the optimum of 250 kgN ha^{-1} or 47 kgN ha^{-1} to bring the application up to the typical figure of 197 kgN ha^{-1} (table 7.5).

However, the 150 kgN ha^{-1} being returned to the soil from the red clover/ryegrass crop will be subject to emissions of 5.48kg CO_2 e for every 1 kg returned. Therefore the only saving that is being made is the emissions resulting from the manufacture of the fertiliser that is being saved (3kg CO_2 for every 1kg saved) – in this case 3 x 150, **which equates to a reduction in emissions of 450kg ha^{-1} of CO_2 equivalent or 13.5tonnes of CO_2 e for the farm per year**.

To apply this **pan Wales**, if a red clover/ryegrass crop were to precede the 14812 ha of winter wheat grown, a saving of **6.67 Kt CO_2 e** would be made.

[104] Briggs S, Cuttle S, Goodlass G, Hatch D, King J, Roderick S & Shepherd M. - Soil Nitrogen Building Crops in Organic Farming, OCW 2008.

7.3.3 *Clover/Cereal Bicropping*

Clover-Cereal Bicropping is the practice of drilling winter cereals into a permanent, perennial understore of white clover, to provide N and a range of other benefits to the cereal crop.[105]

The clover is cut for silage in the autumn and following this, winter wheat is direct drilled into the cut clover sward in October. The wheat and clover develop together over the winter and the bicrop is given 50kgN ha^{-1} in early May. The crop can either be cut as wholecrop silage, which returns a similar yield as for conventionally grown wholecrop silage, but with reduced N cost of 200kgN ha^{-1} at optimum application rate or 147kgN ha^{-1} at typical application rate. Growing wheat as part of a bicrop would therefore reduce N to the spring application of 50 kgN ha^{-1}, which is 1.25 t CO_2 e $ha^{-1}yr^{-1}$**.**
However, it should be noted that when harvesting for grain, the yield is only 60% of conventionally grown wheat.

Using the HGCA greenhouse gas calculator, the average wheat crop in Wales emits 434kg CO_2 e per tonne of grain produced. Using the bicropping system the average wheat crop in Wales would emit 270kg CO_2 e per tonne of grain produced, a saving of 164kg CO_2 e per tonne.

According to the Welsh agricultural statistics[106] for 2005, 14812ha of wheat was grown, producing 105200 harvested tonnes.
If we assume that all this was winter sown and that the average crop yielded 7.1 t ha^{-1}, the potential yield using the bicropping method would be 4.26 t ha^{-1} (60% of conventional. There would have been a shortfall in wheat production of 42100 tonnes.

Emissions from 2005 conventional production would have been:
105200 x 434 = **45.66 Mt CO_2 e**

Emissions if bicrop method used at 60% yield:
105200 x 60% = 63120 x 270 = **17.04 Mt CO_2 e**

Theoretically, if we expand this figure to provide the full tonnage produced in 2005, emissions from bicropping would have been:
17.04/60 x 100 = **28.4 Mt CO_2 e – still almost a 50% reduction in emissions for the same yield.**
However, it must be noted that 40% more land area would have to have been in winter wheat production to enable this.

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105 Clover – Cereal Bicropping – R.O. Clements and G. Donaldson, IGER 2002
106 Figures are for 2005, Welsh Agricultural Statistics 2006.

7.4 Evaluation of potential take up of actions identified

All three scenarios are possible on all arable farms, but either requires financial investment or have implications for substantially reduced yield. The arable industry is relatively small in Wales and typically the average farm size is too small to justify anything with large financial implications without some form of capital grant scheme.

The arable industry within Wales, as in the rest of the UK, has suffered from poor grain prices in the last 10 years. The biofuel industry and market has taken off however, consequently the demand for cereals and osr has dramatically increased. Any proposal which results in a reduction in yield will therefore be unpopular with producers.

Nitrogen sensors are very expensive costing in the region of £12000-20000. For the majority of farming businesses this initial cost would be prohibitive and the cost benefit to the business insufficient to make the purchase viable as a large cropping area is needed for cost effectiveness. Contractors could adopt these systems, but most farmers already own some form of fertiliser spreader themselves. Contractors usually spread the farmers' nitrogen fertiliser rather than providing it themselves, leaving no incentive for the contractor to buy such a tool. A change in management practice to allow the contractor to provide both the fertiliser and the equipment would be the only viable way forward and any savings by using the equipment would be directly passed to the farmer.

Introducing a Red Clover/Ryegrass ley into a rotation has many benefits other than the reduced N requirement, however many farmers would be reluctant to leave a proportion of their productive land out of production for a year, unless they already had livestock to feed or had the land in rotation as part of an organic system. The cost benefit of reduced emissions would not outweigh the cost of a 'missed year' of cropping, particularly in light of the increased demand for crops as discussed above and it is unlikely that this will change on arable farms until the cost of agrochemical feltilisers become prohibitive. There is also a knock on effect of reduced domestic yield, possibly leading to increased imports. In order to take full advantage of this system a change back to mixed farming systems of livestock and crop production would be necessary.

Bicropping is a novel way of cropping and better suits an organic system, which cannot apply synthetic fertiliser. However, achieving only 60% of usual potential yield would be unacceptable to most farmers and uptake is therefore likely to be low for the same reasons as mentioned above. Many farmers see artificial N as a necessary part of modern agriculture. Any reduction in yield as a result of a reduction in N applied would be considered absurd practice in the conventional arable sector. If practised across Wales, bicropping would lead to a reduction of 42000t of wheat produced and the shortfall would have to be supplied from the rest of the UK or abroad. There are transport, financial and emissions costs associated with this, which may be higher than using a conventional growing system locally.

7.5 Knowledge gaps and constraints

It is difficult to quantify reductions precisely, as there is insufficient information available about emissions from the key components of the arable industry. The calculations that have been made here are often based on assumptions, and this has been made clear in the text.

It was noted during research for this section that papers often show contradicting evidence. Zero or minimum tillage in particular requires more research to identify the benefits and costs to the environment from both above and below ground processes. There are mixed messages over its effect on carbon sequestration, overall fuel usage (including extra applications of pesticides etc.), nitrous oxide emissions (from less aeration) etc. that must be clarified.

Controlled traffic farming is very similar to zero or minimum tillage but uses GPS to continually use the same tramlines year on year. This technique is still in its infancy and requires more research to fully understand its benefits.

The HGCA greenhouse gas calculator appears to make many assumptions and its figures are more geared to the larger, predominantly arable farm of the lowland Eastern England type, with larger more efficient machines and larger fields/area to distribute costs amongst. This type of farm is infrequent in Wales due to topography and tradition and therefore the actual carbon footprint of wheat in Wales may well be higher that predicted by HGCA’s calculator.

8 Horticulture

8.1 Key Emissions

The main source of emissions from horticultural cropping is from fertilisers and pesticides[107] and although application of these to conventional field vegetables is often high, there is similarity in scale to that of arable crops.[108] As emissions from fertiliser and pesticide use has been explored in the sections of this report on cropping and nutrient management, it will not be revisited here.

8.1.1 Greenhouse gas emissions from protected horticulture

Protected edible crops emit CO_2, CH_4, and N_2O[109] at up to 50 times more per ha than field crops. In contrast to field horticulture, where CH_4 and N_2O represent a significant part of total emissions, CO_2 is the single most important greenhouse gas produced by protected horticulture, resulting from the combustion of fuels for heating and for increasing CO_2 concentrations in the greenhouse to stimulate crop growth. Tomato production in particular requires greater inputs of natural gas and fertilisers and thus produces more CO_2 emissions per hectare than the greenhouse horticultural sector as a whole. Whilst there are currently only around 37ha of protected cropping in Wales[110], it is envisaged that this will increase as policy is implemented to source more locally produced food. Also the predicted increase in outside temperatures driven by climate change is expected to reduce the amount of heating necessary for glasshouses, thus increasing profitability and decreasing emissions.

On average, protected edible cropping, heated and lit by oil and gas boiler systems, currently uses 4.45 GWh $ha^{-1}yr^{-1}$[111], so if the 37ha in Wales was all heated cropping, it would use 164.65 GWh yr^{-1}. At a GWP of around 56 tCO_2 equivalent / GWH Welsh protected horticulture would produce 9.22 $ktCO_2$ e yr^{-1}.

Table 8.1 suggests that if Short Rotation Coppice (Combined Heat & Light) was used as a glasshouse energy source the emissions produced would be 21 to 51 tCO_2 e ha^{-1}. For Wales' 37ha this would mean a saving of 7.4 to 8.4 $ktCO_2$ e yr^{-1} (80 to 91%). When compared with the projected % savings of other measures suggested in table 8.1, the possible impact is obvious.

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[107] CALU (2007) *Scoping the Environmental and Social Footprint of Horticultural Food Production in Wales*
[108] CALU (2007) *Scoping the Environmental and Social Footprint of Horticultural Food Production in Wales*
[109] CALU (2007) *Scoping the Environmental and Social Footprint of Horticultural Food Production in Wales*
[110] Agricultural Small Area Statistics 2005
[111] Warwick HRI 2007

Table 8.1 –% Measures for energy & carbon savings in protected horticulture (5207 GWh total energy use for the 1792 ha protected crops in the Uk), includingl payback period and potential barriers to adoption of these measures[112] (full table at Annex 5).

Energy-saving boiler measure	Potential energy savings	Total C savings ($ktyr^{-1}$) for 1792ha GH crops in UK	Payback period (years)	Barriers to take-up
Improved greenhouse cladding and reduced air leakage	230 GWh 4%	13	2-5	Investment in new glasshouses
Improved design (including flue gas condensers)	230 GWh 4%	13	2-5	High capital cost. Only practical with gas, and where low grade heat can be utilised.
Thermal screens	240 GWh 5%	14	2-5	High capital cost. Cultural resistance in edibles sector.
Temperature integration and climate control	800 GWh 15%	45	2-5	Technology transfer needed. Research gaps.
CHP installation (fossil fuel)	1,050 GWh 20%	60	5-10	High capital cost. Electricity requirements have to be high or there is export potential
In Comparision:		Total C saving (Kt/yr) -Wales only		
SRC CHP boiler installation for all of Wales 37ha of protected crops	80 – 91%	7.4 – 8.4	Not calculated	High capital cost. New technology so tech transfer needed. Cultural resistance

However, the other initiatives identified above will also contribute to GHG reductions, for example, even the use of CHP generators burning fossil fuels could reduce emissions by 60%. As this sector is currently so small in Wales this has not been explored further, but the implications for the UK as a whole are much more significant - Welsh production horticulture is only 0.7% of the whole UK sector.

8.1.2 Waste Plastics

Greenhouse & tunnel film, mulch & crop cover, fertiliser bags, propagation materials, product packaging are waste streams which contribute to the 5% of UK waste plastics from agriculture as a whole, with the majority from horticultural production. Table 8.2 shows the tonnage of plastic waste produced in the UK – in Wales the highest tonnage is of fertiliser bags, with crop cover and other horticultural plastics having together the next highest impact.

[112] Warwick HRI 2005

Table 8.2. Estimated tonnes of selected plastic waste produced in the UK, England, Wales, Scotland and Northern Ireland in tonnes per year (1998). Source: Defra (2003b)

	UK total	England	Wales	Scotland	Northern Ireland
Greenhouse and tunnel film	500	468	10	12	11
Mulch film and crop cover	4500	3738	30	657	76
Mulch film and crop cover + contamination	22500	18689	148	3283	380
Other horticultural plastics	6000	5617	114	143	127
Plastic agrochemical packaging	2400	1720	30	276	374
Plastic fertiliser bags	12200	8748	984	1654	815
Plastic seed bags	1000	840	15	134	12

It is estimated that plastic horticultural mulch waste is 1010kg ha^{-1} for early potatoes, 1020kg ha^{-1} for field vegetables and 1940kg ha^{-1} for soft fruit.[113] Use of biodegradeable mulch covers has been compared with conventional covers by Scarascia-Mugnozza *et al*[114], who found that twelve months after tillage, only 4 % of the initial weight of the biodegradable film remained in the soil. No ecotoxicity was found in the soil, and there were benefits of greater yields and earlier harvests compared to traditional plastic films. The biodegradeable film also contributes to the soil carbon content. Life Cycle Analysis of the two systems has not yet been identified to an extent where comparison is possible.

8.1.3 Use of peat and other growing media

The scope of this section is on the impact on GHG emissions of substituting peat growing media with alternatives such as coir / perlite etc. The impact of peat extraction on existing Welsh peat soils as a carbon sink is not addressed as very little peat is currently extracted in Wales – there are currently only 2 small sites - in Anglesey and Carmarthenshire.

In the UK we use around 750,000 m^3 of peat per year for professional horticulture[115], some 22% of the 3.4million m^3 used in total. The rest is used by the landscape sector, amateur gardeners and local authorities. Some is sourced in the UK, with the majority coming from Ireland and the Baltic States. Peat makes up 94 % of growing media used, whereas soil improvers are mainly (92 %) based on alternatives (DETR 2000). The majority of glasshouse crops such as tomatoes are now grown in rockwool[116], but peat is still used widely for salad crops, mushrooms and propagation.

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[113] EA (2005) *Changing attitudes towards waste – Recycling agricultural waste plastic*

[114] Scarascia-Mugnozza, G., Schettini, E., Vox, G., Malinconico, M., Immirzi, B. & Pagliara, S. (2006) *Mechanical properties decay and morphological behaviour of biodegradable films for agricultural mulching in real scale experiment*.

[115] Holmes (2004) *Peat & Peat Alternatives, their Use in Commercial Horticulture in England & Wales in 2003*

[116] www.britishtomatoes.co.uk/newsite/ facts/growing.html

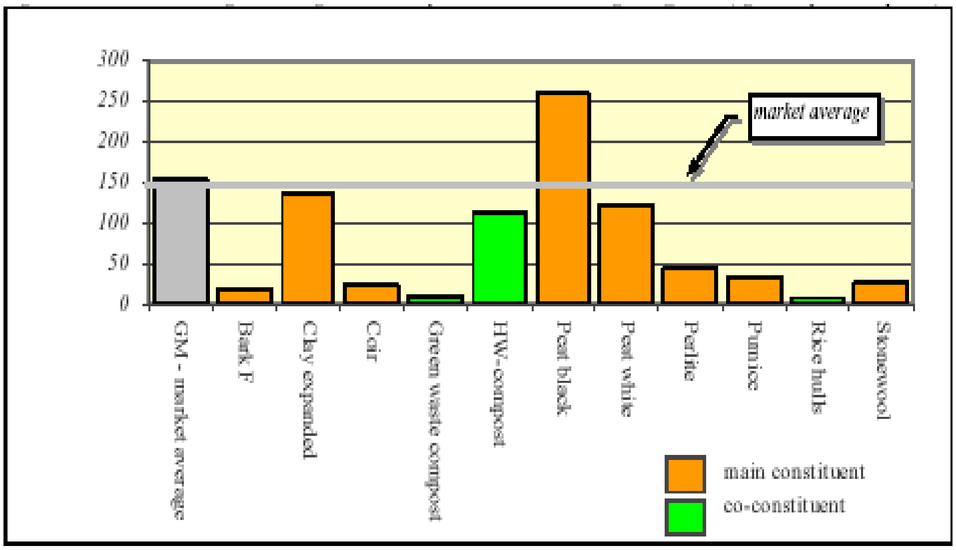
Alternative materials are described in more detail in DETR (2000) and EN (2006) and include bark, coir, wood waste, paper waste, spent mushroom compost, composted waste (e.g. green waste from landscape gardeners), animal manures and inorganic materials (e.g. vermiculite and perlite). In 1993, members of the Peat Producers Association produced more than 100 low-peat or peat-free alternatives[117], including vermicompost, which is the end product of the breakdown of organic matter by earthworms in high densities and can consume a variety of organic wastes, including sewage sludge, animal wastes, crop residues, paper waste and industrial wastes.

A recent study on tomatoes confirmed that vermicompost has the potential to substitute peat in potting substrates because of its stimulatory effects on emergence, growth and biomass allocation of seedlings and the negation of requirement for additional fertilisation.[118] The suitability of other materials as peat substitutes has also been extensively investigated e.g. by Hartz *et al.* (1996), Roe *et al.* (1997), Arenas *et al.* (2002), Evans & Karcher (2004), Hu & Barker (2004), Veeken *et al.* (2004), Kahn *et al.* (2005), Gruda & Schnitzler (2006). However, despite evidence such as this, lack of confidence in and higher prices of peat alternatives has resulted in slow uptake by commercial growers, whose major concerns are cost, quality and consistency. To build confidence in the products, the Compost Association has worked with the Waste Resources Action Programme (WRAP) to develop a standard for compost, and similar work is underway on a standard for sewage sludge. However the NFU believes that at the current rate of development of alternative materials, the Government aim to replace 90 % of the peat used by 2010 is neither achievable nor commercially sensible[119].

The main constraint to obtaining an accurate picture of the impact of peat use on emissions in Wales is that there are no specific data available for peat use in professional horticulture sector in Wales only. The only way to estimate this is to establish the ratio of professional horticulture in the UK as a whole to that of Wales and apply the same ratio to the figure above. The GHG emissions of peat compared with alternative growing media can then be applied to the resulting figure of peat use for Wales using figure 8.1 below.

[117] Robertson 1993 – Peat, horticulture & environment
[118] Zaller 2007 – Effects on gremination, biomass allocation, yields & fruit quality of 3 tomato varieties
[119] www.nfuonline.com/ x1183.xml, 30.11.2006.

Figure 8.1 – Overview of GHG emissions of various constituents of growing media in CO_2 equivalents m^{3-1}



The survey of agricultural and horticultural land use for 2007[120] shows 169,000 hectares of land in horticultural production (vegetables, fruit, glasshouse and horticulture) in the UK, of which 1,210ha is in Wales[121]. A simple calculation gives horticultural production in Wales as 0.7% of the UK total, and apportioned accordingly, Wales uses 0.7% of the 750.000m^3 of peat per year, equating to 5250m^3 $annum^{-1}$.

On this basis, Table 8.3 below illustrates the possible saving in kt CO_2 equivalent if alternative growing media are used: in comparison with the total emissions from agriculture the potential savings are very small.

[120] Defra 2008 – Survey of UK Agriculture & Horticulture
[121] Welsh Agricultural Small Area Statistics 2007

Table 8.3 – GHG emissions (in CO_2 equivalent) if various growing media used for Horticulture in Wales and the potential saving if substituted for all peat used.

Growing Medium	GHG Emissions / m^3 in $KgCO_2$	GHG Emissions ($ktCO_2$ e) for 5250m^3/of growing media used annually in Welsh Horticulture	% GHG Emissions reduction from peat use per year	Actual GHG Emissions less than peat (kt CO_2 e per year)
Peat	260	1.37	-	-
Peat mix (50%)			25%	
Expanded Clay	145	0.76	44.23	0.61
Perlite	50	0.26	80.77	1.11
Coir	25	0.13	90.38	1.24
Bark	20	0.11	92.30	1.26
Green Waste Compost	10	0.05	96.15	1.32

8.2 Evaluation of potential take-up of mitigation measures

8.2.1 Protected cropping

It is unlikely that the 37 ha of protected cropping estimated to be in Wales is all glasshouse. Much of it is be unheated polytunnels, but the data does not provide this split and there is currently insufficient data available from other sources to provide an accurate figure for heated cropping. A project is currently being undertaken by Welsh Assembly Government to compare the various data sources for horticulture in Wales in order to establish the full extent of the horticultural sector and its variances. However, of the 6ha of glasshouse tomatoes known by the author to be grown in Wales, 5ha are grown by one producer[122], who has already expressed interest in using Short Rotation Coppice for Combined Heat and Power. Using the above calculation the 5ha currently emits 1.246 kt CO_2e yr^{-1}. Use of SRC to provide CHP would reduce this by 1 to 1.14 kt CO_2e.

8.2.2 Peat Use

The AHWG (Ad Hoc Working Group) for the revision of the European Eco-label for Soil Improvers and Growing media reached a consensus in 2005[123] that it was not imperative to use peat in soil improvers and it would therefore continue to be excluded from their approved products. However, there were arguments for its continued use in growing media, because in combination with peat, waste products can be more effectively recycled and the high level of potassium in them

[122] Horticulture Strategy Group for Wales, producer information
[123 & 17] SV&A Sustainability Consultants 2005 – European Eco-label for soil improvers & growing media

is balanced effectively with the low levels in peat. A dilution of peat in growing media of 50% - a rate acceptable to growers - would give a GHG emission reduction of 25%. This compromise could be an interim measure to apply to the standards required for growing media to 2020. which would allow sufficient time for alternatives with better and more consistent performance to be developed[124]. If we apply this 25% reduction to the GHG emissions identified in table 2 the total GHG emissions from the horticultural sector could be cut by **0.34kt CO_2 e yr^{-1}**, with of course a knock-on effect of reduction of GHG emissions from peat use by the remainder of the users – the amateur gardening sector, private sector landscapers and local authority maintenance.

The biggest challenge - ensuring that all growers move over to peat-free or low-peat alternatives may only be achievable by legislation or government support, but the promulgation of initiatives such as EN and RSPB's 'Peatering out – towards a sustainable UK growing media industry'[125], which explores alternative growing media to protect remaining peatlands and highlights how peat use could be ended in 10 years in the UK, can provide a 'bottom up' approach, by giving consumers a chance to change growers' attitudes. On the 'Peatering Out' website, a service is provided for finding the producers and sellers of plants grown in peat-free media. Several major multiple retailers in the UK have also introduced policies of peat reduction, e.g. Marks & Spencer and Homebase (Holmes 2004).

8.3 Other Opportunities to Mitigate Emissions (covered in other sections on cropping)

There are several measures which can reduce emissions, although for some options, there is lack of knowledge of the overall effects.

Measures which are predicted to reduce emissions are:

- Use of nutrient planning to enable minimum applications of fertilisers: – reduction in emissions from manufacture of product & packaging and CO_2 / N_2O at application stage.
- Reduction of energy use by correct machinery operation & selection – correct size for operation, education of operators to use efficiently, etc
- Reducing heat input by heating only in winter months, or by short season cropping in summer months only – but with implications for overall productivity and profitability
- Development of supply systems which minimise need for cold storage of produce
- Inclusion of cover crops in growing cycle to enhance carbon sequestration.
- Inclusion of cover crops in growing cycle to enhance nitrogen sequestration resulting in lower requirement for agrochemicals.

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[125] www.rspb.org.uk/ Images/peateringout_tcm5-31088.pdf

- Use of biodegradeable plastics and alternative products
- Efficient recycling of plastic products provided the recycling uses less energy than using virgin plastics.

Measures where the benefits for greenhouse gas emissions are unclear include:

i. Conservation (zero) tillage where reduced emissions from (i) fuel used to till and (Iii) soil carbon losses are balanced by the energy requirement for greater agrichemical input (weed control and fertiliser input due to the competition from the vegetation already in situ). In addition there is growing evidence that zero tillage increases the emissions of nitrous oxide, outweighing the reduction of emissions of carbon dioxide from the absence of tilling[126].

ii. organic production where although there is a reduction of emissions linked to input of agrochemicals, this is balanced by an increase in use of organic fertilisers, and higher emissions per unit of output due to lower productivity of organic systems. In the case of tomatoes, organic production yields about 75% of conventional production, and the resulting greater area required to meet the same rate of production will increase the energy inputs. Cranfield University has estimated GHG emissions for the current mixture of tomato types grown in organis systems is almost twice the emissions from current conventional mix of tomato types[127].

8.4 Constraints

A review of the known environmental impacts of horticulture in Wales revealed two major points. Firstly, that compared with other food production systems, such as livestock and arable, relatively little is known about the environmental impact of horticulture in the UK as a whole and secondly, few studies have been conducted on the environmental impact of horticulture in Wales[128]. A particular knowledge gap relates to the impacts of horticulture on greenhouse gas emissions, both directly through on-farm operations and indirectly through use of inputs and storage/packing/transport facilities.

[126] The effects of reduced tillage practices and organic material additions on the carbon content of arable soils - Scientific Report for Defra Project SP0561

[127] Cranfield University report for DEFRA – “Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities” in August 2006

[128] CALU (2007) *Scoping the Environmental and Social Footprint of Horticultural Food Production in Wales*

A key constraint is the lack of baseline statistics for the sector. Land used to grow potatoes and the majority of horticultural crops has not been historically eligible for CAP support in Wales (although this is due to change). Coupled with the fact that many horticultural producers are small or micro enterprises (SMEs), this has not encouraged producers to register land under the Single Payment Scheme (SPS), or even for the Integrated Administration and Control System (IACS) to register as an agricultural holding.

The Agricultural Small Area Statistics for Wales is also not comprehensive because it is based on a sample from the registered holdings,[129] although it records the larger producers. An example is that the area of potatoes grown in Wales in 2006 according to the agricultural small-area statistics was 2190ha[130] whereas only approximately 70ha are registered annually as potatoes on the SPS Single Application Form (SAF). Therefore whilst the CALU (2007) report provides excellent detail regarding the greenhouse gas emissions for various horticultural activities, it has been unable to accurately quantify the impact for Wales

8.5 Conclusion

The production horticulture sector is a very small proportion of the agricultural sector as a whole in Wales, and as such its GHG emissions are low. Therefore any actions to mitigate these emissions will have a small impact in comparision with actions identified for the rest of the agricultural industry. Nonetheless savings can be made, particularly by encouraging the industry to limit peat use as a result of development of better alternative growing media.

The horticulture sector in Wales is predicted to increase and become more seasonal as the public awareness of food and environment issues rises and local supply networks are sought by retailers. But given that that land of a sufficiently high quality for crop growing is at a premium in Wales, competition from other sectors such as arable, biofuel and biomass crops will constrain growth.

It is difficult to say whether expansion will have a positive or negative impact on GHG emissions without taking into account the full life cycle analysis of local production, which includes many variables such as: the reduction in food miles from growing more produce here instead of importing; the impact on soils of increased cropping; the prospect of an increase in protected cropping and the increase in the domestic horticulture sector.

Information about the horticulture sector in Wales is limited, even to the extent of establishing its true size and this also needs to be addressed.

[129] WAG Statistics Unit
[130] Welsh Agricultural Statistics 2006

8.6 Knowledge gaps

- Derive better baseline data on activities and extent of the sector in Wales
- Understand the patterns of greenhouse gas emissions from field and protected cropping in order to research and develop ‘low carbon’ horticultural systems.
- Develop management systems for minimising greenhouse gas emissions in horticultural systems, particularly potatoes and protected cropping.
- Undergo better research into the development of low peat content growing media to produce a medium with high reliability and low cost factors acceptable to the industry.
- Undertake LCA comparisions of plastics and plastic alternatives used by the industry
- Support techniques which work towards achieving carbon neutral status for protected crops (such as woodchip CHP units)

9 Biomass / Biofuels / Microgeneration / Anaerobic Digestion

Developing renewable energy sources, for example by growing energy crops on farm, can provide several benefits. Crops can be used to supply local energy generation plants (on or off farm); to offset the carbon emitted from farm energy use; can provide additional income if selling either the crop or excess electricity/heat off farm and can also contribute to reducing the wider GHG emissions for Wales compared to fossil fuel use.

9.1 Background

9.1.1 Biomass

Biomass is the biological material derived from living, or recently living organisms. In the context of biomass for energy this often used to mean plant based material, but biomass can equally apply to both animal and vegetable derived material. This report is concerned only with the product of the photosynthetic process and associated plant derived biomass used for energy production, e.g. woodfuel, short rotation coppice and grasses such as Miscanthus and Reed Canary Grass.

Biomass can be used as fuel for burning to produce heat and / or electricity or it can be base material from which combustible oils are extracted. Its use as a solid fuel can be large scale such as purpose built wood-fired power stations or smaller scale providing heat and power to single or small groups of buildings (combined heat and power or 'CHP'). Energy generation from biomass and waste is more flexible to demand than some renewable sources such as wind energy.

Significant carbon savings can be achieved by replacing oil-fired heating plants with biomass fired plants[131]. In the context of reducing emissions from agriculture, the savings are achieved by using domestically grown energy crops. This, however does not take into account the harvesting, processing or transport involved with either energy crops or fossil fuels. It is essential therefore to use full life cycle analysis (LCA) to compare the GHG emissions from fossil and biologically derived fuels produced both domestically and outside the UK.

The information on the lifecycle of fossil fuels and renewable energy, especially biomass and biofuels is considerable, and has been growing rapidly over the past few years. Elsayed (2003)[132] has collated information on life-cycle analysis (LCA) from other literature sources providing a table of GHG emissions for biomass and

[131] Biomass sector review for the Carbon Trust (2005). Carbon Trust.
[132] Elsayed, MA, Matthews, R. & Mortimer, ND. (2003). Carbon and energy balances for a range of biofuel options. Project Number B/B6/00784/REP.

biofuel technologies - see Tables 9.7 and 9.8. A report[133] for the Scottish Executive has also reviewed the literature and summarised information on general potential, GHG emissions and energy balances, air quality and associated environmental technologies. This study provides details of the GHG balances of other renewable technologies which have been used in Table 9.3.

Taking account of high carbon content of organo-mineral soils and the loss of carbon on initial cultivation and planting, the overall GHG balance remains positive. An estimate for miscanthus is that the overall GHG balance for conversion from grassland over a 15 year rotation is:

Loss of soil carbon emissions - 25.4-27.2 t CO_2 e ha^{-1}.
Production/processing emissions - 14 t CO_2 e ha^{-1}.
Fossil fuel substitution emission savings - 213-243 t CO_2 e ha^{-1}
Net emissions reduction - 171.8-201.8 t CO_2 e ha^{-1}.

These values compare with sequestration of grassland of **19.3 t t CO_2 e ha^{-1}** over 15 years, if left undisturbed. For conversion from arable, using Hansen's estimate of 51.3 t CO_2 e ha^{-1}, **the net emission reduction would be 250.3-280.3 t CO_2 e ha^{-1}**

Table 9.1[134] below shows the energy use of average farms in Wales.

Table 9.1 Typical energy usage on farms per year

Typical electricity usage (Enterprise)	**Average Range (kWH)**	**GHG Emission per unit (kg CO_2 e)**
Dairy (per cow)	273 - 434	422 – 672
Beef (per head)	36 - 63	56 – 97
Sheep (per head)	9 - 16	13 – 24
Arable (per ha)	66 - 225	102 – 349
Grain drying (per tonne)	41 - 123	65 - 191
Typical fuel usage	**Average Range (litres)**	**t CO_2 eGWh ha^{-1} [3]**
Glasshouse heating (heating oil/ha)	123,582 - 297858	0.58 – 1.39

[1] 0.16 grid primary energy [need to convert by multiply by 0.43, not 0.16]
[2] Arable = root crops, cereals
[3] (litres x 38) x 0.2778

There is limited information available for the use of heat on-farm as it is provided by electricity in the majority of cases. However, given heat requirements in the husbandry of pigs, broilers and heating water for dairy parlours, there is potential

[133] Review of Greenhouse Gas Life Cycle Emissions, Air Pollution Impacts AND Economics of Biomass. Production and Consumption in Scotland. (2006) Scottish Executive.
[134] CALU (2007). Managing Energy and Carbon: The Farmers' Guide to Energy Audits. ADAS energy audit statistics.

for biomass heat utilisation. It is also worth considering the potential heat demand for some farm diversification enterprises e.g. office or tourist accommodation.

A recent study carried out by Technical Services Division has estimated that there are approximately 628,000 hectares of land suitable for growing energy crops in Wales. This excludes environmentally sensitive designations; unsuitable soil types and steep slopes. It is not intended to suggest that all this land could or would be planted, merely that it is suitable from an agronomic point of view and does not have protection as 'habitat' under designation, legislation or agri-environment agreement.

Forestry Commission statistics[135] are that the total available amount of farm woodland in Wales is 41,700 hectares[136]. However, this includes areas which may have limited or no accessibility and it does not take into account environmental constraints. As a rough estimation, this area would produce 83,400 oven dried tonnes (odt) annually, based on a rate of 2 odt of wood fibre per hectare of native broadleaf. This excludes branches which increases the yield by a further 31%. According to the Forest Research Woodfuel calculator[137] the proportion of the tree which lies in the stem is 78% stem wood >18cm; 13% stem wood between 14 – 18cm and 9% is small diameter stem wood. Although the stem wood in total can be used, the wood >18cm and larger is also suitable for other products and would be better utilised in this way with the resultant co-products used for energy production.

Therefore if assuming 50% of the >18cm wood that could be used for energy production, the yield of farm woodland which could potentially go in to energy production is 24,036 odt annually. This would deliver 0.029 TWh electricity annually or 0.097 TWh as heat – based`on a calorific value of 20 Giga-joules/odt, 25% conversion efficiency for electricity and 85% conversion efficiency for heat[138]. The electricity output would reduce emissions by 12470 – 15631 t CO_2 e compared with supply from the National Grid.

9.1.2 Liquid Biofuels

For the purposes of this study, biofuel is taken to be either biodiesel or bioethanol. Biodiesel can be produced from animal fats, vegetable oil or recycled cooking oil. Most of the small scale production of biodiesel in Wales is from recycled cooking oil, but there is growing interest in vegetable oil primarily from the crushing of oil seed rape (OSR) and esterification. Bioethanol is a result of fermentation and distillation of wheat, barley or sugar beet. Both of these biofuels are currently produced at a commercial scale in the UK.

[135] Chris Edwards personal communication
[136] June census
[137] www.forestry.gov.uk/woodfuel/FWSPECIES
[138] Woodfuel resource in Britain B/W3/00787/REP, URNo3/1436. H McKay 2003

The following table[139] indicates that biofuels have a lower energy content than fossil fuels.

	Calorific Value (GJ tonne^{-1})
Mineral Diesel	42.7
Biodiesel	37.7
Petrol	41.3
Bioethanol	26.4

However, given the current low blending % of biofuels with fossil fuels, this drop in energy is masked in terms of energy efficiency in vehicles. Vehicles fuelled with a 5% blend of biodiesel (B5) or 5% bioethanol (E5) showed few differences in terms of engine performance. Engine power was found to improve at 100% bioethanol but fuel economy declined by 25% - offset by the lower price of the fuel at the pump.[140]

Second generation biofuels are being developed - examples are based on ethanol from ligno-cellulose ethanol and synthetic fuels from conversion of biomass to liquid fuels produced by the Fischer-Tropsch process. First generation biofuels, being sold as blends with fossil fuel at the pump, are very compatible with the current fuel infrastructure and require little or no alteration of the engine. Although perhaps not as efficient as second generation biofuels in relation to utilising feedstock, they are a useful stepping stone in biofuel use, providing at least some GHG savings, particularly while second generation biofuels are still being developed.

The second generation biofuels could be available in the next 5 years[141]. The advantage of these fuels is that they utilise the total crop e.g. straw as well as seed. Volkswagen has suggested that second generation feedstock can provide over three times the yield of first generation crops[142]. The Fischer-Tropsch process also allows the gasification of woody biomass, such as short rotation coppice, converting the gas into high quality diesel fuel. This step away from food crops towards lignocellulosic crops would reduce the competition for prime growing land, thus reducing conflict in the food versus fuel debate.

Studies on the cost abatement of biomass use for energy indicate that transport fuels are the least cost effective, causing them to be placed at the bottom of the hierarchy of cost-effective carbon abatement[143]. A Royal Society report[144] suggests that most biofuel programmes are aimed at increasing the use of

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139 Review of GHG life cycle emissions, air pollution impacts and economics of biomass production and consumption in Scotland - Scottish Executive and Rural Affairs Dept - 2006
140 Newsletter Issue 6 - National Non-food crops Centre - 2006
141 Climate change: the role of bioenergy (2006). House of Commons. 8th report of session 2005-06.
142 Volkswagen evidence provided to the House of Commons Environment, Food and Rural Affairs Select Committee.
143 UK Biomass strategy - Defra - 2007
144 Sustainable biofuels: prospects and challenges (2008). The Royal Society.

biofuels from an energy security perspective. However, this could result in missed opportunities to reduce greenhouse gas emissions and develop new technologies that are efficient and environmentally beneficial. Biofuels on their own cannot provide a sustainable transport system but must be part of an integrated transport system.

Table 9.2[145] below shows the average annual fuel use for farm types in Wales and the GHG emissions in kg CO_2 equivalent.

Table 9.2 Typical fuel usage on farms per year and equivalent GHG emissions

Enterprise	Average Range (litres)	GHG emissions[1] (kg CO_2 e)
Dairy (farm vehicle fuel per cow)	44 - 90	145 – 298
Beef (farm vehicle fuel/hd)	7.5 - 14.9	25 - 49
Sheep (farm vehicle fuel/hd)	2 - 4	7 - 13
Arable (farm vehicle fuel/ha, ex grain drying)	123 - 236	407 - 780
Grain drying (fuel/t, 3% mc)	8.5 - 12	28 - 40

[1]Based on kg eq CO_2/MJ from Elsayed (2003)[146]
mc = moisture content

9.1.3 Microgeneration

There is an opportunity on farm to employ other microgeneration technologies such as use of solar panels for heat, hot water or photovoltaic (PV) power production; ground source heat pumps; mini-hydroelectric generation and windpower. Some of these technologies can be used to generate electricity both for use on the farm and to sell excess to the national grid. Sale off-farm is a way to offset on-farm emissions.

Within the residential sector, zero carbon definitions for new buildings are defined by the Department of Communities and Local Government within their Code for Sustainable Homes (CSH) as follows:

- **Level 5** - where there are zero carbon emissions from heating, lighting, hot water etc,
- **Level 6** - where there are zero emissions from Level 5 plus all appliances.

[145] CALU (2007). Managing Energy and Carbon: The Farmers' Guide to Energy Audits. ADAS energy audit statistics.
[146] Elsayed, MA, Matthews, R. & Mortimer, ND. (2003). Carbon and energy balances for a range of biofuel options. Project Number B/B6/00784/REP.

The ability to generate sufficient renewable energy will become a key factor for compliance with CSH Level 6. A similar performance rating could be set as the objective for new farm buildings, and then extended to existing buildings.

A review of carbon reductions in new non-domestic buildings indicates the following costs for renewables, based on full up-front costs by a developer[147]. In practice the developer may use an Energy Supply Company to provide some if not all of the funding of the infrastructure in return for the revenue of running that infrastructure.

Renewable	**Cost of Implementation (£/kg CO_2 avoided per year)**
Solar PV	14.78
Small scale wind	12.50
Biomass CHP	1.15
Large scale wind	1.02

Examples of the additional costs of renewables for typical buildings such as primary schools which have Level 6 performance are:

Primary School Renewable Type	**Average Renewable capital cost (£/square metre)**
Small Scale wind	£300
Solar PV	£390
Biomass CHP	£30
Large Scale wind	£30

The results show the economic advantages of Biomass CHP and Large Scale wind.

These results have been confirmed in a separate study on the domestic sector by the Renewables Advisory Board[148]. The report concluded that biomass CHP is likely to be the first technology to considered where wind energy is not viable, because of its relatively low capital cost, and its ability to meet power and heat loads under zero carbon regulations. But the high uptake of biomass CHP is critically dependent on the technological development of sub 1MW plant. The uptake is also dependent on the attractiveness of communal heating, and the avoidance of air quality impacts from emissions.

Zero carbon standards will drive high uptake of solar PV in residential buildings because it requires no additional space, and can be integrated in to the fabric of

[147] Report on carbon reductions in new non-domestic buildings. DCLG and UK Green Building Council. December 2007

[148] The role of on-site energy generation in delivering zero carbon homes. Renewables Advisory Board 2007.

buildings. Electric heating may be favoured where large scale wind power is available, because of its simplicity and low cost. Solar water heating is useful for raising levels of renewable use, where there is significant water use eg dairying. Heat Pump installations are also not favoured because they increase the need for on-site renewable electricity production.

In another report carried out by the Energy Savings Trust[149] several Welsh scenarios are presented on the take-up of different technologies as a result of government policy. The report states that, without government assistance, combined heat and power (CHP) will dominate microgeneration by 2020, with ground source heat pumps, biomass and solar heating still offering signification reductions in CO_2 emissions. The expected CO_2 savings under this base scenario are 0.2 Mt CO_2 e yr^{-1} by 2030 and 0.7 Mt CO_2 e yr^{-1} by 2050. With appropriate government policies the report states that microgeneration in Wales has the potential to save 0.6Mt CO_2 e yr^{-1} by 2030 and 1.4Mt CO_2 e yr^{-1} by 2050 - representing 6% and 14% of current domestic emissions respectively. Government policies could include capital subsidies; market support and Renewable Obligation Certificates which provide funding based on the electricity generated.

Comment [Julie5]: What is this?

The report states that active solar heating is more economic in new builds and that renewable heat generation (solar water heating, ground source heat pumps and biomass) will achieve market penetration in areas off the gas supply network (which the majority of farms are). Market penetration of Solar Photo-Voltaics (PV) is limited due to the high capital cost, although with government intervention this may improve. Micro-hydro is constrained by lack of appropriate sites, but it is likely that many suitable sites for micro-hydro will be available on agricultural land. The 2001 resource report[150] outlined that there were around 200 schemes in Wales ranging from small systems for domestic supply to 50 MW systems connected to the grid. Their contribution was estimated at 210 GWh yr^{-1}. Potential in 2001 was estimated to be a further 200 MW rated capacity for small-scale hydropower schemes in Wales.

As a result, within the farming sector, we forecast that the take-up of solar water heating, ground source heat pumps and biomass will be significant as it is envisaged that market penetration of these will be high in areas off the gas grid. Large scale wind has a good potential, if used for exporting power to the grid, but small wind generation has relatively poor potential on a cost-benefit basis. Micro-generation schemes have the potential to reduce the carbon footprint from energy use, and where there is provision of power to the National Grid, to help in offsetting the other GHG emissions from farms.

[149] Potential for Microgeneration in Wales Study and Analysis. Draft results pack (2007). Energy Savings Trust.
[150] Strategic Study of Renewable Energy Resources in Wales (2001), Sustainable Energy Ltd.

9.2 Key emissions

9.2.1 Biomass

Conceptually the production of biomass is carbon neutral, i.e. the crops will absorb as much CO_2 when growing as is expended in its processing and use for fuel. However there are GHG emissions associated with it - the key emissions being CO_2 and N_2O. CO_2 is released from the use of fossil fuels from machinery used to plant, harvest and transport the material[151]. These emissions could be mitigated through energy efficiency improvements and fossil fuel substitution with biomass or biogas. However this is an area that offers few overall potential savings[152] (see Arable Section 7).
Also there will be a small amount of CO_2 released as a result of the carbonisation of carbon into the atmosphere from soil cultivation (Soils Section 4).
N_2O is released as a result of fertilisers used to grow the crops or remnant fertiliser in the soils being released (see Manures and Fertilisers Section 5). The advantage of SRC and Miscanthus crops is that there is minimal use of fertilisers, pesticides or herbicides, which means that the N_2O emissions of the crop is low.

A Scottish Executive report[153] states the balance of GHGs for several energy technologies, both renewable and fossil fuels (see Table 3 below). This shows that biomass heat, electricity and combined heat and power technologies result in considerable savings in GHG emissions and fossil fuel[154].

Table 9.3[155] Greenhouse gas emissions for renewable technologies and fossil fuels

Greenhouse Gas Balance	**GHG Emissions in kg CO_2 e MJ^{-1}**		
Fuel Source	**Heat**	**Electricity**	**CHP**
Grid electric	0.16	0.16	0.16
Oil	0.122		
LPG	0.10		
Natural Gas	0.082		
Straw	0.018	0.065	0.05
SRC wood chip	0.005	0.02	0.01
Forest wood chip	0.005	0.02	0.01
Solar water	0.006		

151 Biomass sector review for the Carbon Trust (2005). Carbon Trust
152 Papers from Rural Climate Change Forum 06/09. Market Based Mechanisms For Greenhouse Gas Reductions In The Agriculture, Forestry And Land Management Sector.
153 Review of Greenhouse Gas Life Cycle Emissions, Air Pollution Impacts AND Economics of Biomass. Production and Consumption in Scotland. (2006). Scottish Executive.
154 Taking into account both direct inputs from consumption of fuels and electricity and indirect inputs as a result of the provision of materials and equipment.
155 Prosser, H. (2007). Bio-energy – Environmental Policy Analysis AND Review of Greenhouse Gas Life Cycle Emissions, Air Pollution Impacts and Economics of Biomass, Production and Consumption in Scotland. (2006). Scottish Executive.

Solar PV	0.03	0.03	
Small-scale hydro	0.002	0.005	

A report produced for the Department of Business, Enterprise and Regulatory Reform (BERR)[156] provides further detail for SRC and Miscanthus (Table 9.4).

Table 9.4 Greenhouse gas emissions for different technologies for renewable fuels

Technology	**Total GHG (kg CO_2 e / MJ produced)**
CHP gasification of SRC*	0.004-5
Electricity by combustion of Miscanthus	0.026
Electricity by combustion of SRC**	0.023-25
Electricity by gasification of SRC**	0.007-8
Electricity by pyrolysis of SRC**	0.015-16
Heat from wood chip boiler*	0.007

* Small scale
** A range of results for harvesting and chipping combined and baling and transporting for chipping.

9.2.2 Liquid Biofuels

The total UK CO_2 emissions from road transport in 2005 amounted to 120 MtC per annum, which is 21% of the UK's total emissions[157]. According to the Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland: 1990-2005[158] the CO_2 output for Wales is just over 6 MtC for 2005.

The growing of biofuel crops for transport fuel can contribute to the reduction in the overall emissions from Welsh transport, as well as reducing emissions from fuel usage within agriculture. The key GHG emissions of biofuel production are CO_2 and N_2O. The N_2O emissions are a result of the fertiliser use on biofuels crops, which is a lesser studied aspect of biofuel production. Conceptually, the production of biofuels is carbon neutral i.e. the crops will absorb as much CO_2 as expended in its production and use. However the emissions from the production of the feedstock needs also to be taken into account. More importantly, the energy used to produce fertilizers and pesticides adds substantially to the emissions.

Several life-cycle analyses have been carried out on GHG saving as a result of the production of different biofuels. The savings have been measured against the

[156] Elsayed, MA, Matthews, R. & Mortimer, ND. (2003). Carbon and energy balances for a range of biofuel options. Project Number B/B6/00784/REP.
[157] National Statistics Office, for 2005
[158] Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland: 1990 –2005. Report to Department for Environment, Food and Rural Affairs, The Scottish Executive, The Welsh Assembly Government and The Northern Ireland Department of Environment.

production of the equivalent fossil fuels. However, the results of these studies vary for different fuels, dependent on the methods used. The Global Bioenergy Partnership (GBEP), which is made up of the G8 countries, intends to harmonise the various methodologies used to conduct LCA of biofuels[159] in order to produce consistent results.

The Royal Society states that wood for electricity generation offers 3 to 5 times the GHG savings per hectare compared with biofuels derived from food crops and more than twice that of biofuels from lignocellulose. This is however dependent on factors such as yield of feedstock, conversion efficiency, process chosen and which fuel is being displaced.

A research study into the environmental impact of growing wheat and oilseed rape for biofuels concluded that: "Compared to fossil-derived petrol, bio-ethanol from wheat has the potential to reduce energy inputs by 61% and total GHG emissions by 65% for each MJ of energy created. Bio-diesel from oilseed rape has the potential to reduce energy inputs by 66% and total GHG emissions by 53% for each MJ of energy created.[160]

Table 9.5, from the Sustainable Biofuels: Prospects and Challenges Report[161], demonstrates the energy and GHG savings from several biofuel crops and different production systems compared to two fossil fuels.

The table demonstrates that there is variation in GHG emissions between different biofuels. The GHG savings will depend on how co-products are used, the type of agriculture and how the conversion processes are powered. In order to achieve the greatest savings, policy is required to incentivise combinations of the production processes which deliver the greatest greenhouse gas savings[162].

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159 Sustainable biofuels: prospects and challenges (2008). The Royal Society.
160 An Assessment of the Potential Environmental Impacts Arising from Cultivation of What and Oilseed Rape for Liquid Bio-fuel production - CSL - 2005
161 Sustainable biofuels: prospects and challenges (2008). The Royal Society.

162 Sustainable biofuels: prospects and challenges (2008). The Royal Society.

Table 9.5 Comparison of energy and greenhouse gas savings for different crops and production systems (reproduced from Sustainable biofuels: prospects and challenges

Feedstock	Co-product use	Growing method	Process inputs – heat & power	GHG emissions (g CO_2 e / MJ produced	% GHG savings / MJ produced
Ultra-low-sulphur diesel [(a)(1)(m)]				87.6	
Unleaded petrol [(b)(1)(o)]				81.5	
Bioethanol					
Starch (wheat grain) [(d)(o)]	Distillers' dark grains and solubles (DDGS) use as animal feed	Conventional [(e) (q)]	Natural gas-fired process heat, grid electricity	63.5	22
	DDGS use as animal feed	Conventional [(e) (q)]	Natural gas-fired process CHP	52.1	36
	DDGS use as animal feed	Conventional [(e) (q)]	Straw-fired process CHP	36.7	55
	DDGS use as animal feed [(p)]	Conventional [(e) (q)]	Straw/coal-fired process CHP	11.6	86
Biodiesel					
Plant oils (oilseed rape)	Rape meal used as animal feed [(f) (m)]	Conventional [(hxy)])	Natural gas -fired process heat, grid electricity	46.3	47
	Rape meal used as animal feed [(g) (m)]	Low-nitrogen [(Ixq)]	Natural gas-fired process heat, grid electricity	29.9	66
	Rape meal used as animal feed and co-firing [(g) (m)]	Low-nitrogen [(Ixq)]	Rape straw/coal-fired process CHP	26.2	70
	Rape meal used only for co-firing [(g) (n) (r)]	Low-nitrogen [(Ixq)]	Rape straw/coal-fired process CHP	-5.6	106[(k)]

(a) Ultra low sulphur diesel produced in the UK with a net calorific value of 42.38 MJ/kg.(b) Unleaded petrol produced in the UK with a net calorific value of 43.99 MJ/kg.
(d) Wheat yield of 8.60 t/ha/yr at 20% moisture content.
(e) 185kg N/ha/yr application during cultivation. Average EU-15 soil emissions of 2.23kg N_2O/ha/yr for wheat cultivation.
(f) Oilseed rape yield of 3.07 t/ha/yr at 15% moisture content. (g) Oilseed rape yield of 2.92 t/ha/yr at 15% moisture content.
(h) 196kg N/ha/yr application during cultivation. Average EU -15 soil emissions of 3.12kg N_2O/ha/yr for oilseed rape cultivation.
(I) 81kg N/ha/yr application during cultivation. Average EU-15 soil emissions of 3.12kg N_2O/ha/yr for oilseed rape cultivation.
(J) Assumed Global Warming Potentials of 23kg eq. CO_2/kg CH_4 and 296kg eq. CO_2/kg N_2O (IPCC 2001).
(k) Net savings exceed 100% due to credits from the displacement of a UK mix of electricity generation.
(l) Excluding vehicle combustion CH_4 and N_2O emissions. (m) Mortimer *et a*l (2003). (n) Mortimer *et a*l (2003). (o) Mortimer *et al* (2004). (p) Punter *et a*l (2003)
(q) Edwards *et al* (2006). (r) Mortimer & Elsayed (2006).

9.3 Implementation issues

9.3.1 Biomass

Land use

One option for use of biomass is for co-firing with coal to be used at power stations for electricity generation. One estimate is that this would require 238,000 odt annually. It is estimated that another 108,000 odt is required for local CHP schemes and heating systems.

Conversion of biomass to heat is very efficient (up to 90% efficiency) whereas electricity production is a very inefficient process (20-30% efficiency)[163]. Co-firing of biomass with coal to produce electricity is favoured by the current ROCs, and from April 2009 to March 2016, there is a requirement for a rising percentage of biomass to be derived from crops specifically grown for energy use. However, there is no stipulation as to the source/distance from end-user. Experience in Northern Ireland indicates that transport costs for SRC are prohibitive for more than 30-60 miles. Given the position of Welsh coal-fired power stations at Aberthaw and Uskmouth, the transport costs for locally produced biomass are likely to be high, and the energy balance poor.

For local markets for CHP and heat, the requirement for domestically grown crop is 108,000 odt - equivalent to around 9,000 hectares. If the total 9,000 ha is grown for energy crops this could save 11,700 $tCO_2\ yr^{-1}$ from fossil fuel electricity generation or 132,300 $tCO_2\ yr^{-1}$ from heat generation from oil[164].

This increase in energy crop production will result in the possibility of ploughing up of permanent pasture. The consequences for soil carbon emissions has been discussed further in Section 4.

In order to limit the GHG emissions from establishment and growing of energy crops through to harvesting, mitigation measures can be used such as correct use of machinery, fertilisers and manures and soil carbon management, all of which are covered in other sections.

There are other ways to reduce the amount of GHG emissions from the production of energy crops, for example to grow woodland to offset CO_2 generated on the holding (see Section 4) and to implement minimum tillage operations (Section 8).

Husbandry issues

SRC crops require specialist machinery for harvesting of crops. The machinery currently used is large-scale machinery suitable for the flat plains of northern European countries. This equipment is not suitable for most of the potential growing area in Wales due to topography and historically smaller

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[163] DTI Future Energy Solutions, 2005

[164] Alun James (personnel communication). 14.7 tCO_2 /ha from oil heating and 1.3 tCO_2 /ha from fossil fuel electricity production.

field size. However, there are developments in this area which will address this issue.

9.3.2 Liquid biofuels

Land use

There have been no official projections of the amount of biofuel crops which could or should be produced in Wales. Table 6 shows the amount of land put down to arable crops in Wales in 2005 and the total amount of biofuel this would produce.

Table 9.6 Production of wheat and oilseed rape in 2006

Total crop 2005 ha[165]		Biofuel capable of producing (million litres)	GHG output (kt CO_2 e[166])	
Wheat	14,812	33.84[167]	Bioethanol	37.29
Oilseed rape	2,959	4.03[168]	Biodiesel	6.28

In Wales, 61,000 ha of land is down to arable or fallow production, therefore the 38,000 ha needed to meet the 5% ROC rate is possible without encroaching on permanent pasture. If this area was put down to OSR it would equate to a 12-13 fold increase in OSR grown in Wales.

Any increase in growing crops for biofuels in Wales will depend on other demands for arable areas such as the development of the horticulture sector and demands for cereals for human and livestock food. The Home Grown Cereals Association (HGCA) feel that it is likely that the market will respond to increased demand by producing more grain, probably at a higher price[169]. There is some concern at the pressures on land in the UK as a whole as a finite resource. A balance between production of food and fuel in order to provide security of supply of both is needed and this will not be easy to predict in light of climate change expectations in relation to drought, temperatures and severe weather conditions.

Given other pressures on arable areas such as the need for home-grown feed grain as feed prices increase and forage maize for the dairy industry, it is possible that temporary grassland may come under the plough for cropping purposes. This will have knock-on consequences for permanent grassland as grass yields come under pressure to meet the shortfall in temporary grassland. This element will need to be closely monitored, as Single Farm Payment rules restrict ploughing of permanent pasture (over 5 years old) to

[165] Welsh Agricultural Statistics 2006 (2007). Welsh Assembly Government National Statistics.
[166] Elsayed, MA, Matthews, R. & Mortimer, ND. (2003). Carbon and energy balances for a range of biofuel options. Project Number B/B6/00784/REP.
[167] www.esru.strath.ac.uk/EandE/Web_sites/02-03/biofuels/quant_bioethanol.htm. 1t = 0.336 m^3
[168] Booth E, Booth J, Cook P, Ferguson B, and Walker K. (2005). Economic Evaluation of Biodiesel Production from Oilseed Rape grown in North and East Scotland.
[169] Making sense of Biofuels (2007). HGCA Factsheet.

10% of 2003 levels and could also see an increase in applications under the Environmental Assessment Regulations (EIA) 2002 to bring semi-improved grassland into more intensive production .

The associated increases in fertiliser use and soil cultivation will have an impact on diffuse pollution as well as GHG emissions.
As mentioned for biomass, certain measures can be taken to reduce carbon emissions e.g. correct use of machinery, fertilisers and manures and soil carbon management. Some processors e.g. Greenenergy have already introduced certification or assurance schemes requiring growers to record fuel and fertiliser used to grow the crops.

Consideration will also be needed to the distance from production to processor. At present there are no crushing facilities in Wales. However planning permission has recently been granted for a crushing plant in Cardiff to Flex Fuels, who have expressed an interest in sourcing around 100,000 tonnes of oilseed rape from within Wales[170].

Husbandry issues
Oilseed rape requires specialist machinery e.g. sprayers and swathers in its production. Owing to the capital investment involved, most arable farmers here rely on contractors. As crop area increases it will be more viable for contractors to invest in the provision of this machinery. However, lack of available in machinery will also be a limiting factor in farmers' decisions to grow OSR, leaving a 'chicken and egg' situation.

It is likely that drying and storage facilities will need to increase on farms depending on the scale of their current arable enterprise. The need to dry crops on-farm will also depend on proximity to processors and the facilities they provide.

Certification schemes
Both the European Commission and UK government have indicated that a method of independent certification will form an important part of their biofuels strategy. Confirming the details of the RTFO in the April 2006 Budget Statement, the UK Government announced that it has asked the Low Carbon Vehicle Partnership to lead on work looking at the issue of carbon and sustainability assurance[171]. More recently DfT has set up a study on sustainability of biofuels – due to report in summer 2008.

9.4 Conclusions

At present, growing energy crops is not economically attractive for farmers. The level of subsidy for break even is estimated to be well above the level of around £1000/hectare to support the establishment of either short rotation

[170] Draft Consultation on a Bioenergy Strategy for Wales(2007). Welsh Assembly Government.
[171] UK Treasury (2006) Budget Report

coppice or Miscanthus. This cannot be achieved under Axis 1 of the RDP, which limits grant aid to 40% of actual establishment costs.

There are good arguments for bringing existing farm woodlands into management and using wood arising from that management to fuel local, small scale heat plants. Bringing these woodlands into management could provide an additional source of income for the farmer and improve the environmental value of the woodland as well as contributing to carbon reduction through the substitution of a fossil fuel with wood. One option is to seek Forestry Commission help with developing a variant of their current woodland management grant scheme that specifically targets support for farmers who wish to bring their woodlands into management to produce woodfuel.

The Energy Route Map has recognised the potential opportunities for farmers in Wales to support the production of first generation biofuels. However any support is expected to focus on innovative projects which represent a step forward in terms of improving existing technologies. Development of markets is a key aspect to be achieved. Given concerns about the sustainability of first generation biofuels, consideration has to be given to the GHG balance of the entire biofuel chain. This means that projects will need to be exemplars in terms of sustainability e.g. based on local feedstocks which have been produced sustainably and do not involve major land use changes or negative impacts on biodiversity.[172] Research at IBERS to develop grasses with dual functions of nutrition and feedstock for ethanol represent a potentially important avenue for expanding the area of Wales suitable for biofuels.

9.4.1 Microgeneration

The take up of renewable generation options are limited at present but there are examples of farms employing small hydro scheme and a combination of solar panels and wind power. This has been used where farms are off the national grid.

As an example, for an average dairy farm of 119 milking cows as the biggest user of electricity according to Table 10.1, to provide total requirement for electricity on an average dairy farm would require a turbine(s) with an output of 22KWh (at 22 % load factor).[173] This would require grid electricity as back-up for meeting demand when wind conditions are poor.

9.5 Greenhouse Gas Emissions Tables

Table 9.7 shows the amount of GHG (kg CO_2 equivalent MJ^{-1}) which is produced from the enterprises listed in Table 9.1 above. The kWh unit has been converted into MJ (1 kWh = 3.6 MJ) and litres into MJ (1 litre = 38 MJ)

[172] Biofuels - current policy position - Transport Wales 2007
[173] 354 (ave) kwh/hd x 119 = 42126 kwh. 42,126 x (24 hrs x 365 days) x 22% = 21.86 kwh

and multiplied by the relevant factor of GHG emissions from the life-cycle analysis of different technologies as shown by Elsayed *et. al.* Table II. (2003)[174] and multiplied by the number of stock or hectares grown in Wales in 2005.

Table 9.8 shows the amount of GHG (kg CO_2 equivalentsMJ^{-1}) which is produced from the enterprises listed in Table 9.2. The litres have been converted into MJ (1 litre = 38 MJ) and multiplied by the relevant factor of GHG emissions as calculated by Elsayed *et. al.* (2003)[175] and multiplied by the number of stock or hectare grown in Wales in 2005.

Table 9.9 shows the total GHG emissions from grid electricity (total GHG emissions from fossil fuels from Table 10.1 multiplied by the total head, ha or tonne) and the GHG emissions savings from the use of SRC and Miscanthus (the total GHG emissions for SRC and Miscanthus in Table 9.7 subtracted from column 1 of Table 9.9).

Table 9.10 shows the total GHG emissions from fossil fuels for transport fuels (total GHG emissions from fossil fuels from Table 9.2 multiplied by the total head, ha or tonne) and the GHG emissions savings from the use of OSR for biodiesel and wheat for ethanol (the total GHG emissions for OSR and wheat in Table 9.8 subtracted from column 1 of Table 9.10).

Table 9.7 Greenhouse gas emissions if biomass technologies used in farm production - per year in CO_2 equivalents

Sector (Wales)	**GHG output if electricity generated from SRC[1] (kt CO_2 e)**	**GHG output if electricity generated from Miscanthus[1] (kt CO_2 e)**
Dairy (264,403hd)	6.76 -10.74	6.50 - 10.33
Beef (220,745hd)	0.74 - 1.30	0.86 - 1.50
Sheep (4,116,433)	13.87 - 24.27	13.33 - 23.34
Arable (41515)	0.24 - 0.83	0.23 - 0.80
Grain drying (5.6t x 41515ha)	0.88 - 2.64	0.85 - 2.54
Typical fuel usage per unit	**Equivalent GHG output from SRC[2]**	**Equivalent GHG output from forest residue[3]**
Glasshouse heating (heating oil/ha) (37ha)	0.78 – 1.9 (kt CO_2 e)	1.22 – 2.92 (k t CO_2 e)

[1]Electricity generated from combustion
[2]CHP
[3]Wood chip heat only

[174] Elsayed, MA, Matthews, R. & Mortimer, ND. (2003). Carbon and energy balances for a range of biofuel options. Project Number B/B6/00784/REP.

[175] Elsayed, MA, Matthews, R. & Mortimer, ND. (2003). Carbon and energy balances for a range of biofuel options. Project Number B/B6/00784/REP.

Table 9.8[176] Greenhouse gas emissions of renewable fuels used in farm production - per year in CO_2 equivalents

Sector (Wales)	GHG output from OSR biodiesel (kt CO_2 e)	GHG output from ethanol from wheat (kt CO_2 e)
Dairy	17.68 – 36.17	12.38 – 25.32
Beef	2.52 – 5.00	1.76 – 3.50
Sheep	46.93 – 93.23	32.85 – 65.26
Arable ha	7.39 – 14.18	5.17 – 9.93
Grain drying	2.96 – 4.18	2.07 – 2.93

Table 9.9 The total GHG emissions from grid electricity and the difference between the total GHG emissions from grid electricity and SRC from combustion and Miscanthus from combustion.

Enterprise	GHG emissions from grid electricity (t CO_2e)	Difference in GHG for SRC	Difference in GHG for Miscanthus
Dairy (264,402 hd)	41.58-66.10	34.82 - 55.36	35.08 - 55.77
Beef (220,745 hd)	4.58 - 8.01	3.83 - 6.70	3.72 - 6.51
Sheep (4,116,433 hd)	21.34 -37.94	17.87 - 31.78	18.00 - 32.01
Arable (41515 ha)	1.50 - 5.12	1.26 - 4.29	1.27 - 4.32
Grain drying (5.6t x 41515ha)	5.41 - 16.25	4.54 - 13.61	4.57 - 13.71

[1]0.16 grid primary energy
[2] Electricity from combustion

Table 9.10 The total GHG emissions from fossil fuels and the difference between the total emissions from fossil fuels and OSR for biodiesel and wheat for ethanol.

Enterprise	GHG emissions from fossil fuels (t CO_2 e)	Difference in OSR for biodiesel	Difference in wheat for ethanol
Dairy (264,402 hd)	38.46 - 78.67	17.68 - 36.17	12.38 - 25.32
Beef (220,745 hd)	5.47 - 10.87	2.52 - 5.00	1.76 - 3.50
Sheep (4,116,433 hd)	27.22 - 54.44	12.51 - 25.03	32.85 - 65.26
Arable (41515 ha)	1.61 - 30.85	7.39 - 14.18	5.17 - 9.92
Grain drying (5.6t x 41515ha)	6.44 - 9.10	2.96 - 4.18	2.07 - 2.93

These tables show that there could be considerable savings in GHG emissions from using biomass and biofuels compared to that of fossil fuels. With regards to the biomass, it would appear that there is not much variation

[176] Elsayed, MA, Matthews, R. & Mortimer, ND. (2003). Carbon and energy balances for a range of biofuel options. Project Number B/B6/00784/REP.

between the combustion of SRC or Miscanthus. The use of combustion is one of the most inefficient ways of generating heat and power; however, it is currently the most developed technology. With regards to biofuel, per unit of production ethanol from wheat produces less GHG emissions than biodiesel from OSR. Again these technologies are the best developed technologies for the production of biofuels, however second generation biofuels offer significant GHG savings[177], if they become available in the next five years.

9.6 Constraints and key knowledge gaps

There are limitations to the data used in this paper. There appear to be no papers related directly to electricity and fuel use in farms, other than the data collected by ADAS[178], which enable calculations of GHG emissions on a whole farm basis. This paper has also relied on literature which has collated LCA information and has not sought to review the initial LCA information due to time limitations. This could result in an element of error, as the information will have been derived using different assumptions. However where possible, inconsistencies in the data have been minimised.

There is no information available regarding the differences in energy use between lowland and hill or conventional and organic systems. However, it may be assumed that energy use would be similar as there is not necessarily any requirement for more energy use between these systems. The number of tractor passes when growing conventional crops, for instance, will be similar to organic as although there is no agrochemical use, organic fertilisers are used along with mechanical weed control.

The data used for GHG emissions is not specifically based on on-farm use of homegrown energy crops, but on larger scale use of the crops. On-farm use of homegrown crops is likely to lead to lower emissions due to the reduction in transportation. The emissions from use of home grown vs. 'imported' crops (from other farms in Wales, wider UK and the continent) should be compared.

Further work to ascertain the life cycle analysis of small scale microgeneration should be carried out to provide a more accurate picture of emissions savings.

9.7 Evaluation of likely delivery of the identified actions

In order to encourage the use of renewable energy generation on-farm, or to grow material for energy production off site, incentives will need to be provided. The current energy market is providing an incentive for renewables.

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177 Climate change: the role of bioenergy (2006). House of Commons. Eighth report of session 2005-06.

178 CALU (2007). Managing Energy and Carbon: The Farmers' Guide to Energy Audits. ADAS energy audit statistics.

Financial incentives such as an energy crops scheme to encourage farmers to grow energy crops are being considered within the Axis 2 review. Other options are to support market development to enable the purchase of boilers for on-farm use, or for energy generation companies to be able to install the required infrastructure. There is advice available for small-scale infrastructure, however, this needs to be more accessible.

9.8 Anaerobic Digestion

9.8.1 Introduction

Anaerobic digestion (AD) is the biological conversion of organic matter in the absence of oxygen into methane, carbon dioxide and hydrogen. This product is termed biogas. The biogas can be used for heating and/or electricity production, and therefore substitutes for fossil fuels. The residual liquor can be used a liquid fertiliser, and the residual fibrous material as a soil conditioner.

In terms of climate change mitigation, the AD process has potential benefits in reducing methane emissions from manure storage and spreading, and substituting for fossil fuels in energy production. Manure emissions are 7% of Wales' total agriculture emissions of 1.64 Megatonnes Carbon – ie 0.115 Megatonnes Carbon in 2005.

Other benefits of AD are:
- the reduction of pathogens and faecal indicator organisms which can pollute water courses
- stabilisation of organic matter, reducing chemical and biological oxygen demand in water courses
- increased availability of nutrients by converting less available organic nitrogen to ammoniacal nitrogen
- conservation of fertilizer nutrients (N, P and K) from the raw manure, reducing the need for artificial fertilizer use and associated emissions from manufacture
- better infiltration/incorporation of manure into soil, reducing leaching and run-off.

9.8.2 AD Processes

An AD system typically consists of
- a reception pit or tank for short term storage and homogenisation of slurry,
- a silo digester which is a gas tight tank with a mixing system to keep the slurry homogeneous, and a heat exchanger system to maintain a uniform process temperature
- a gas holder to receive the biogas (it is impractical to liquefy methane)
- a receiving tank or lagoon for digested slurry with the option of a centrifuge to produce a soil conditioner and a nutrient-rich liquor.

Other systems in use include

- Covered lagoons with no heating or mixing facilities, for solid contents of 2% or less
- Silo tanks for solid contents of 2-10%,
- Plug flow tanks for higher solid contents of 11-13%.

9.8.3 Process Control

Digestion takes place in four stages, with typical process times of 20-30 days.

- Hydrolysis where micro-organisms break down the organic wastes into sugars, amino acids and fatty acids
- Fermentation to form a range of organic acids, carbon dioxide and hydrogen
- Acetogenic stage where acetogenic bacteria convert the organic acids to acetates, carbon dioxide and hydrogen
- Methanogenic stage where methanogenic bacteria convert acetates to biogas comprising methane (50-70%), carbon dioxide (30-40 %), hydrogen (5-10%) and trace amounts of hydrogen sulphide and mercaptans.

Farm-scale digesters are usually based on single stage vessel using a mesophilic process – operating at about 33-45^{0}C. Apart from farm wastes, AD can also use food wastes, and biodegradable municipal waste. These wastes have important advantages in providing concentrated additional energy to drive the microbial processes. For food wastes, the Animal By-Product Regulations require AD plants to process the waste at least 70^{0}C for 1 hour in a closed system. Raising the temperature to about 55-60^{0}C leads to a faster process (thermophilic) but requires additional energy to heat the process

The stability of the anaerobic process requires careful management, because it is necessary to maintain the balance between several microbial populations. Hydrolysis and fermentation stages have the most robust organisms, whereas the methanogenic bacteria are very sensitive to acidity, operating only in the pH range of 6.5 to 7.5. Maintaining a uniform loading rate to the digester is a critical factor in maintaining the correct pH. If conditions become too acidic, lime may need to be added as a neutralising agent. This requires a steady source of manure, which may be difficult to achieve where there are seasonal variations in availability of manure, for example, if relying on one source such as dairy cattle.

Temperature control is important for maximising gas production. For mesophilic processes, maximum conversion is around 35^{0}C. In the UK climate, this requires supplementary heating to maintain steady temperatures. This is important when starting the digestion process, which requires a few weeks before steady gas production occurs.

9.8.4 Use of Biogas

Biogas can be used as produced for cooking and heating. But it contains hydrogen sulphide which is corrosive in boilers and internal combustion engines, leading to early failure. Hydrogen sulphide can be removed by injecting less than 6% volume of air, by adding iron chloride to the digester inflow, or flowing the biogas through wood chips impregnated with iron oxide, or through activated carbon.

For effective mitigation it is important that that there is a market for the biogas. At roughly 60% methane content the biogas has about 60% of the calorific value of natural gas. Typically one fifth of the energy in the biogas is needed to maintain the necessary temperature of the digester, leaving the remainder for replacing fossil fuels. The main value is in using biogas for direct heating but it can also be used for electricity generation. In the farm situation, demand for heat can be low, whereas electricity can be exported via the national grid. However energy conversion to electricity is low – typically 35%. In the UK, market economics favour electricity production where energy output exceeds farm heat requirements because the electricity generated by AD is eligible for Renewable Obligation Certificates. BERR has proposed that the rate of Renewable Obligation Certificates for anaerobic digestion should be 2 units per MWh until 2013.

Typical biogas generation rates[179] are summarised here:

Table 9.11. Biogas generation rates for animals

Animal	Biogas Production Rate (Cubic Metres/Day)
Hens	0.015
Fattening pigs	0.14
Sows	0.2
Fattening cattle	1.0
Heifers	0.85
Milking cows	1.2

The potential for biogas production can be estimated from animal populations. Agricultural statistics data for Wales are summarised in Table 9.12.

Table 9.12 Animal Populations in Wales - 2005

Animal	Populations in Wales (2005)
Dairy cattle (breeding herd)	264,403
Beef cattle (breeding herd)	220,745
Total cattle and calves	1,240,765
Total pigs	28,363
Laying hens	1,507,493
Table chickens	4,998,651

The UK methane recovery potential has been estimated to be 1004 kt CH_4 yr^{-1}, equivalent to 21084 kt CO_2 e yr^{-1}[180]. This is 28.2% of the theoretical

[179] FEC Services. Anaerobic digestion, storage, oligolysis, lime, heat and aerobic treatment of livestock manures. Scotttich Executive (2003)

[180] P Mistry, T Musselbrook. Assessment of methane management and recovery options for livestock manures and slurries. Defra Report Ed 05180 (2005)

quantity, because of the difficulties of collecting manure from pasture land. The technical potential for collection from poultry has been estimated to be 54.7%, from dairy cattle 29.1%, from other cattle excluding calves 6.8%, from sheep 0%, and from pigs 26%. Based on the inventory emission estimates for Wales the resulting technical potential for anaerobic digestion to reduce methane emissions is summarised in Table 9.13.

Table 9.13 Estimate of methane recover potential by anaerobic digestion in Wales

Animal	**Technical Emission Saving Potential (Kilotonnes Carbon/year)**
Dairy Cattle	21.06
Other Cattle	6.98
Poultry	1.81
Pigs	0.13
Total	29.98

The total of ca 110 kt CO_2 e yr^{-1} for Wales compares with an estimate of 2181 kt CO_2 e yr^{-1} for emissions savings in the UK[181]. Additional carbon emission saving occurs from the substitution of biogas for fossil fuels used for heat and electricity production, since biogas combustion is rated as a zero emission. The 110 kilotonnes carbon dioxide equivalent equates to 5238 t methane. This would save annual net emissions of 9.45 kt CO_2 e yr^{-1} if converted to electricity and heat in a centralised AD facility.

At an operational level DEFRA has examined AD plants in two categories:

a. On-Farm AD plants (OFADs). A DEFRA study of two units showed that they had poor efficiency, poor temperature control, and high leakage rates. The main reasons for poor uptake of on-farm AD units were the poor economic return due to high capital costs with little or no income to cover costs, and technical problems compounded by lack of operational knowledge and poor availability of technical support. Mechanical problems were common, often resulting from the corrosive sulphide gases in biogas.

b. Larger Centralised AD (CADs) facilities that supplement farm manure and slurry with imported feedstock. Blending of manure/slurry with other organic wastes enhances biogas yields and operational efficiency since food wastes tend to have greater biogas yield potential than farm slurry. The biogas is a fuel for generating electricity, heat or steam that can be used on farm, in local industries or community heating. One CAD plant is operating at Holsworthy in Devon, where it utilises manure from 30 farms together with food waste.

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181 J M Moorby, D R Chadwick, D Scholefield, B J Chambers and J R Williams. A review or research to identify best practice for reducing greenhouse gases from agriculture and land management DEFRA October 2007

A CAD plant that utilises farm slurry will typically have additional waste offloading, reception and storage facilities, plus blending and pasteurisation equipment. CADs have major operational advantages over OFADs due to:

- Economies of scale
- Access to a more continuous supply of feedstock via blending. (The problem with farm slurry is that it is normally unavailable in Summer when livestock are outdoors, although some intensive pig systems have animals housed throughout the year.)
- Better opportunities to use specially trained personnel.
- Ability to blend manure with other waste to improve gas yield.
- Receipt of gate fees for accepting waste that may otherwise be subject to landfill tax e.g. biodegradeable municipal waste, food waste
- Scope for commercial exploitation of gas and heat generated by the AD process.

9.8.5 Economics

As an example, the DEFRA report estimated capital costs an OFAD plant for a 168 dairy cow herd are about £150K, with annual operating costs of about £3K. On an annual basis, net methane production is 17560 cubic metres, generating 62,829 KWh of which 50,260KWh would be exported. This would produce an income from electricity sales and ROCs of £4.2K (Ref 2). Net carbon dioxide reduction would be 14 tonnes per year from the electricity credit.

The costs of the Centralised AD plants have also been estimated, based on for a unit handling manure from about 19,200 dairy cows, 23,343 other cattle, 34,740 fattening pigs and 421,277 poultry layers. Annual net methane production would be about 4.35 million cubic metres, producing 15,573 MWh. Total capital costs would be £15.5M. Assuming 10% of the total waste feed came from non-farm sources at a gate fee of £48/tonne, net annual income would be about £1.54M. Net emission reduction from electricity production would be 5,832 tonnes carbon dioxide.

Taking the Centralised CAD concept further, Dairy UK and AEA Energy and Environment[182] have undertaken a feasibility study of 10 potential sites in England and Wales that could host CADs, linked to the dairy-processing sector. Within Wales, agricultural statistics show the main populations concentrations of dairy cattle are in Pembrokeshire and Carmarthenshire (124,900), and North East Wales (48,800) - linked to large cattle numbers in Cheshire and Shropshire.

The report concluded that 3 of these CADs are economically viable with the best giving a payback within 3 years. Annual net carbon savings per plant ranged up to 4000 tonnes carbon dioxide equivalent from electricity production. The study recognises that the cost estimates are based on a

[182] Outline Feasibility Study of CAD Plants Linked to Dairy Supply Chain AEAT/ENV/R/2408: ADAS, AEA Technology & IGER for Defra (2007)

worst-case scenario, given that the price of renewable electricity and landfill gate fees are likely to rise. These CADs are potentially profitable as they can be designed to capitalise on their potential to co-treat organic wastes from industrial dairy sites, slurry from nearby livestock farms and other food manufacturing wastes. They require significant capital investment that varies from £900K to £6,500K. Profitability depends on gaining the full economic benefit of the combined outputs including gate fees, generation and utilisation of biogas, sale of heat and reduced waste sludge disposal costs. At farm level there are reduced fertiliser costs.

Marginal Abatement Costs have been estimated for a range of agricultural mitigation options, showing that CADs have a cost of £16-45/tonne carbon saved, compared with the OFAD costs of £219/tonne carbon saved[183]. Compared with the Shadow Price of Carbon of £95.33/tonne of carbon[184], CADs would be an economically efficient way of reducing overall GHG emissions, whereas OFAD is an very expensive reduction method, and would be need to justified by other benefits e.g. protection of water resources.

Government incentives for using AD come from the ROC, Landfill Tax, and the Enhanced Capital Allowance for energy and water technologies. There is also potential from EU Convergence funding for the capital costs of AD plant. In the longer term, there is also potential for AD to become part of an emission trading scheme, given that it is one of the easier agricultural mitigation options to measure, report and verify[5].

9.8.6 Conclusions

AD has the technical potential for high recovery of methane from farm-based slurry manure systems. In Wales, there is technical potential to reduce annual methane emissions from manure from 421 kt CO_2 e by 109 kt CO_2 e (i.e. 26% reduction) and save emissions of 9.5 kt CO_2 e by substitution of biogas for fossil fuels in electricity production. The total amounts to about 2% of Wales' agricultural emissions.

Economic returns from on-farm AD units are poor, due to lack-of-scale and operational problems. Centralised AD plants can be economic if they attract additional wastes thereby being able to charge a gate fee based on landfill diversion costs. Feedstocks based on a combination of manure with dairy and food wastes from processing companies have economic advantages. Other biodegradable wastes also need to be considered as feedstocks. Capital grants are necessary for these facilities, and Government incentives such as ROCs and landfill tax are important to improve operating income. Emissions trading may also provide incentives in the longer term.

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183 Market Mechanisms for Reducing GHG Emissions from Agriculture, Forestry, and Land Management. NERA report for DEFRA. September 2007.

184 The Social Cost of Carbon and the Shadow Price of Carbon: What they are, and how to use them in economic appraisal in the UK. DEFRA December 2007

Other barriers to expansion of AD[185] are:

- the lack of understanding among planning authorities, regulators and general public,
- status of digestate as a waste, subject to waste management controls,
- complexity of the OFGEM process for obtaining access to the national grid.

Exemplar projects are important to improve understanding and credibility of the process. On digestate standards, EA and WRAP are working on a standard and end-of-waste protocol for finalisation in Spring 2008. Further work is required to evaluate existing AD operations in Scotland, England and Europe, to assit in design exemplar projects which may be set up on Farming Connect demonstration farms or be promoted with other partners for treating a range of biodegradable wastes.

[185] DEFRA Workshop – Increasing the uptake of anaerobic digestion – Exeter. September 2007

10 Discussion and Recommendations

10.1 Data Limitations

Authors have outlined concerns in each chapter regarding the accuracy of both the data collected from research papers and the subsequent calculations from them. The available research shows wide-ranging or even conflicting data regarding emissions from agricultural activities, due to various factors linked to the fact that climate change is a relatively new topic to science. As a result the impact of the actions identified have been quantified as an average potential or a range of figures. This is most evident in the fields of soils and bioenergy. We will be unable to quantify savings more accurately until actions to mitigate GHG emissions are actually in place on farms.

Baseline data has also been difficult to identify in some areas. Identifying the impact of reducing calving age of dairy heifers, for example, can be demonstrated at farm level, but cannot accurately be expanded to a Wales impact as clear figures are not available to show calving age for all farms currently – dairy farms routinely calve heifers in an age range of 2-4 years. Another example is the horticulture sector, which is greatly underrepresented because many producers are small or micro-businesses and so unrepresented in current agricultural statistics.

It should also be noted that some of the actions identified to mitigate GHG emissions from agriculture do not impact the GHGI data, may be difficult to relate to GHGI data or impact GHGI data in an area not related to agriculture. Several examples have been highlighted in the body of this report: the manufacture of agrochemical fertilisers is recorded under industry; electricity used on-farm recorded in power generation and land use change such as grassland to wetland or other semi-natural habitat is not reflected in the Inventory at all.

10.2 Impact of actions identified to mitigate emissions on a Wales basis

10.2.1 Main emission reductions

Table 10.1 shows the potential GHG reduction for Wales of the key actions identified within each sector of the agricultural industry, current and potential delivery mechanisms and crosscutting impacts of the actions.

In terms of potential emissions reduction based on the annual total of 6020Kt CO_2 e, the main options are:

Soils and land use change

1. Avoid soil carbon loss from organic and organo-mineral soils by using ECOSSE recommendations.
2. Expand wetlands and woodlands on marginal land on mineral soils. Potential to reduce emissions by expanding carbon sink – eg 5% reduction from converting 400 hectares of grassland to woodland at a sequestration

rate of 0.74t CO_2 e /year, or converting 840 hectares of grassland to wetland at a sequestration rate of 0.36t CO_2 e /year.

Manures and Fertilisers

1. Match nutrient requirements more closely to crop needs and applying at appropriate times – up to 1.4% emission reduction.
2. More efficient manure management in making full allowance for manure nitrogen supply, and spreading at appropriate times – up to 0.6% emission reduction.

Livestock Management

1. Increase milk yield per cow – up to 1.8% emissions reduction
2. Decrease cow replacement age and/or increase the longevity of dairy cows – up to 0.8% emissions reduction.
3. Increase technical efficiency in beef cattle production – up to 1.4% emission reduction.
4. Increase technical efficiency of lamb production – up to 1.6% emissions reduction.
5. Match feed rates to animal requirements – up to 1.4% emissions reduction for dairy, up to 1.5% reduction for beef and sheep.

Research on crop genetics, animal genetics and dietary additives to reduce emissions is on-going and short-term studies have shown encouraging results. But further research and testing is required to substantiate these findings. This is likely to take several years.

Arable and Horticulture

1. Use of green manures for arable cropping – up to 0.1% emissions reduction
2. Biomass heating for horticulture – up to 0.15% emissions reduction.

Bioenergy

1. Use of biomass crops to provide farm electricity – up to 1.6% emissions reduction.
2. Use of biodiesel or vegetable oil for on-farm fuel – up to 1.7% emissions reduction.

Anaerobic Digestion

1. Methane recovery from dairy farms – up to 1.8% emissions reduction.

10.2.2 Implications for delivering savings

Soils and land use change

In terms of carbon sequestration, land use change from arable or intensive grassland to woodland or semi-natural habitat will have a high impact on emissions given the likely future competition for use of Wales' small area of land suitable for cropping. But it is unrealistic to consider this as a recommended action for mitigation. In fact it is probable that we will be faced with an increase in land used to grow horticulture and bio-energy crops and already farmers are growing more feed crops themselves as a result of grain prices in early 2008. As a result farmers' natural reluctance to lose productive land will be enhanced and more marginal land will be brought into play. The implications for biodiversity may be positive, in that more marginal grassland land may be reverted further to semi-natural, but the planting of woodland on already semi-natural habitats could result in further loss of grassland biodiversity priority habitats such as lowland acid grassland, haymeadow, Rhos pasture etc. If woodland planting of marginal land is to be promoted as a positive action to mitigate GHG emissions, clear guidelines need to be drawn up, perhaps along the lines of an environmental impact assessment, to ensure that valuable habitat is not lost.

Manures and nutrients

Nutrient and resource management are the actions currently most comprehensively delivered; through the Catchment Sensitive Farming (CSF) pilot scheme, Tir Cynnal / Tir Gofal Resource Management Plans and Farming Connect; and there is potential for further delivery already in the wings under the new CSF and FC programmes and the NVZ regulations. Nutrient and resource management planning is seen by the farmer as of cost benefit to the farm business and the positive impact on diffuse pollution enables better compliance with regulatiory obligations. Continued delivery of best-practice information is therefore a win-win action.

Livestock

Increasing milk yield per cow and tailoring livestock diet to needs are both actions with a high impact on GHG emissions, not only for livestock production systems, but in relation to other sectors. These are really just the two main examples of a suite of actions which together increase the technical efficiency of livestock production sufficiently to be of significant impact on methane emissions. In the dairy sector, farmers are already more open to technical improvements, but the real challenge is engaging the majority of beef and sheep farmers, a sector steeped in tradition. The easiest and most effective GHG mitigation option therefore is to increase technical efficiency on dairy farms. Knowledge is already available to implement this, although developments in diets and additives show promise for further reduction of emissions.

Arable and Horticulture

The size of both of these sectors in Wales renders actions to mitigate emissions small in comparison to others, but nonetheless, there are areas such as nutrient management planning where efficiencies can be made, having additional effects in reducing diffuse pollution, soil erosion etc. Research into minimum tillage systems has as yet provided insufficient evidence to show benefits As discussed, increased competition for land use for arable, horticulture and bio-energy crops and demand for increased crop yields overall conflicts with the suggested use of bicropping and green manure techniques as a substitute for fertilisers unless more land is made available for cropping to compensate for the lower yields.

It is important, however, to be aware that the arable and horticulture sectors are likely to grow in total if Wales is to have increased 'food security' and to ensure that this does not have a large impact on GHG emissions. Continued delivery of best-practice information is therefore a win-win action.

Bio-energy

The issue of competition for land suitable to grow food crops and the link to food security means that it is unlikely that sufficient suitable land will become available to grow enough biofuel crops to supply the energy sector (electricity and heat). However, it has been identified that use of Short Rotation Coppice to fuel combined heat and power (CHP) boilers, coupled with use of fuel from farm woodlands, could provide a winning combination. Enhanced provision for woodland planting and management under Axis II agri-environment programmes could provide some incentive to farmers and if coupled with a capital funding programme for farm-scale CHP units and the appropriate knowledge transfer programme, say through Farming Connect, has the potential to be very successful.

Anaerobic Digestion

Farm-scale use of this technology shows poor economic returns, but large-scale centralised AD plants show potential to be economic if they utilise both farm and food wastes, charging a gate fee which takes account of saving in landfill costs. Capital support is necessary, however along with operating support from avoidance of landfill taxes.

Table 10.1 Costs of abatement of abatement options

Abatement Option	Costs of additional abatement (£/t CO_2 e)
Reduce N Fertiliser in arable crops	109
Reduce stocking rates by 25%	205 for dairy, 24 for beef, 45 for sheep
Improve fertility management -dairy	66
Improve milk yield by 30%	19
High Starch diet Maize - dairy	-235
Anaerobic digestion - dairy	219
Centralised Anaerobic Digestion	16-41
Woodland	10-40

NERA has developed a Marginal Abatement Cost Curve based on estimates of costs and benefits, and compared this with the social cost of carbon – around £25 / t CO_e by 2015. Measures which were less than the social cost of carbon were: use of maize silage, reducing some livestock stocking rates, afforestation, improving milk yields and large centralised anaerobic digestion plants. Other measures tended to have much higher costs.

In practice maize silage has not been chosen as a preferred option in Wales because it requires light soils and relatively high growing temperatures. Maize silage reduces methane emissions by about 5% by replacing low grade proteins in grass silage with high starch content in maize silage.

10.3 Impact of actions identified to mitigate emissions at farm level

Example farm types from the Farm Business Survey data have been used to illustrate the impacts of GHG mitigations at farm level. Clearly, the land use change is the most effective on all farm types (less so if starting from marginal land rather than arable or grassland), but in terms of delivery, nutrient and resource management and technical production efficiencies are probably the most effective actions, given that they also have cost benefits to the farm business, are topics which the farmer can easily relate to and are already being delivered to some extent under current programmes. It is important; therefore, to ensure that developing programmes such as the new Farming Connect continue to include these topics. The CALM (Carbon Accounting for Land Managers) carbon calculator is a tool developed by the CLA[186] which audits activities on-farm such as nutrient management, woodlands etc. and provides a carbon footprint which can be used as a baseline for identifying how to reduce emissions by using on-farm best practice. The tool could be used online or by a farm advisor as part of the proposed Farming Connect suite of available technical advice.

10.4 Recommendations

Mitigation

1. WAG to encourage land use change by afforestation or reversion to semi-natural / wet habitats of more unproductive species-poor marginal grassland to create farm sinks (although only the former is currently reflected in the Inventory), through current and future Axis II agri-environment initiatives.
2. WAG to continue to deliver nutrient and resource management planning and best practice advice through current regulation, agri-environment, Farming Connect and other KT programmes. Ensure that adherence to the Code for Good Agricultural Practice (COGAP) remains a prerequisite of Axis II agri-environment schemes and consider inclusion in Tir Mynydd.
3. WAG to deliver technical efficiency methods for the dairy, beef, sheep, arable and horticulture sectors through knowledge transfer mechanisms such as Farming Connect farm development programmes.
4. WAG to encourage farmers to take stock of farm emissions by use of an on-farm carbon-accounting tool such as the Carbon Accounting for Land Managers (CALM) calculator, in conjunction with best practice information through current and future knowledge transfer mechanisms as listed above.
5. WAG to consider support for on-farm CHP units linked with the delivery of land use change such as woodland planting and management.

[186] CLA, NFU, AIC Climate Change Task Force Report 2007

Monitoring, Data and Research

1. WAG to liaise with DEFRA to support and review research on livestock management systems, including diets, livestock management, and nutrient/manure management (eg REDNEX project to reduce emissions in cattle) to the current variable data.
2. WAG to work with DEFRA to support and review research on soil carbon management and impacts of land use management, where current data are variable.
3. WAG to work with DEFRA on economic valuation of the costs and benefits of the reductions options is required particularly where options deliver a range of other benefits such as biodiversity and water quality.
4. WAG to work with DEFRA and other Das to address knowledge gaps in the baseline data available. Many data are UK-wide or for England and Wales jointly. Examples are: the British Survey of Fertiliser Practice (BSFP), which could be extended to a larger sample of Welsh fields; whole farm fuel and electricity use; on-farm use of home grown energy crops; the current extent of the horticulture sector.
5. WAG to work with DEFRA to address knowledge gaps in the GHG Inventory and increase the sensitivity of the GHGI methodology to allow some of the mitigation options identified in this paper to be monitored in terms of tracking their contribution to Welsh GHG emissions targets.

Table 10.2 – Impact of actions identified to mitigate GHG emissions for Wales.

Actions to mitigate emissions from agriculture (highest impact)	Total possible reduction in GWP for Wales (in kilotonnes of CO_2 e) if action taken up by all farmers / producers in each sector	% Reduction of total Wales GWP from Agriculture (2005) – 6020 Kt CO_2 e	Realistic level of takeup of action (%) by farmers / producers (based on existing evidence)	Delivery of actions through current programmes	Future mechanisms for potential delivery of actions	Crosscutting impacts of delivering actions
Soils						
Land use change – all arable to natural habitat / woodland	**702** woody biomass plus **130** soil sink **= 832**	**13.8**	Farm woodland planting has always been popular under WGS and FWPS, but there is reluctance by farmers to undertake this on 'productive' land	Better Woodlands Wales, Farm Woodland Planting Scheme (FWPS)	Continuation and extension of Axis II funding for woodland planting	Implications for biodiversity +ve & -ve), possible farm fuel source
Land use change – grassland to wetland 5ha / farm	**107– 525**	**1.8 – 8.7**	Reluctance by farmers to undertake this on 'productive' land	Reversion categories available under Tir Gofal / Tir Cynnal	Continuation and extension of Axis II funding	+ve implications for biodiversity, diffuse pollution control
Nutrient / Resource Management						
Do not exceed nutrient requirements for crops and ensure precision application	**81** (5% reduction in NO_2) – note that this action may not be applicable to producers in all sectors	**1.4**	Up to 80% (Evidence from CSF)	CSF development project, Pontbren, Farming Connect, Tir Cynnal & Tir Gofal RMP	KT such as Farming Connect, funding thru Axis II (CSF, TC, TG). NVZ, Tir Mynydd	Reduction in diffuse pollution, cost benefits to farmer
Make full allowance of manure N supply	**12** (5% reduction in NO_2)	**0.2**	Up to 80% (Evidence from CSF)	CSF development project, Pontbren, Farming Connect, Tir Cynnal & Tir Gofal RMP	KT such as Farming Connect, funding thru Axis II (CSF, TC, TG). NVZ, Tir Mynydd	Reduction in diffuse pollution, cost benefits to farmer
Spread slurry/	**5 – 24** (2 – 10%	**0.1 – 0.4**	Up to 80% (Evidence	CSF development	KT such as	Reduction in

Actions to mitigate emissions from agriculture (highest impact)	**Total possible reduction in GWP for Wales (in kilotonnes of CO_2 e) if action taken up by all farmers / producers in each sector**	**% Reduction of total Wales GWP from Agriculture (2005) – 6020 Kt CO_2 e**	**Realistic level of takeup of action (%) by farmers / producers (based on existing evidence)**	**Delivery of actions through current programmes**	**Future mechanisms for potential delivery of actions**	**Crosscutting impacts of delivering actions**
manure at appropriate times & conditions	reduction in NO_2)		from CSF)	project, Pontbren, Farming Connect, Tir Cynnal & Tir Gofal RMP	Farming Connect, funding thru Axis II (CSF, TC, TG). NVZ, Tir Mynydd	diffuse pollution, cost benefits to farmer
Ensure that slurry/manure is appropriately stored	All sectors could consider this method although mitigation methods may only apply to some sectors		Up to 80% (Evidence from CSF) cost dependent e.g storage facilities	CSF development project, Pontbren, Farming Connect, Tir Cynnal & Tir Gofal RMP	KT such as Farming Connect, funding thru Axis II (CSF, TC, TG). NVZ, Tir Mynydd	Reduction in diffuse pollution, cost benefits to farmer
Production						
Increase milk yield per cow	**106**	**1.8**	General trend to less producers / larger herds / higher yield in recent years. Dairy farmers very receptive to technical improvements	Farming Connect Dairy Development Centre (Gellis Aur) is well-respected as a source of technical information	Farming Connect technical advice	Lower stock numbers = less slurry / diffuse pollution.
Decrease cow replacement age from 2.5 to 2 years	**50**	**0.8**	Dairy farmers very receptive to technical improvements	Farming Connect Dairy Development Centre (Gellis Aur) is well-respected as a source of technical information	Farming Connect technical advice	Lower stock numbers = less slurry / diffuse pollution.
Improve technical efficiency in beef cattle production – 10% CH_4 reduction	**83**	**1.4**	B & S sector less receptive to technical efficiency, harder to displace tradition	Delivery thru B & S development centres for Farming Connect	Farming Connect technical advice	Lower stock numbers = less manure / diffuse pollution.

Actions to mitigate emissions from agriculture (highest impact)	**Total possible reduction in GWP for Wales (in kilotonnes of CO_2 e) if action taken up by all farmers / producers in each sector**	**% Reduction of total Wales GWP from Agriculture (2005) – 6020 Kt CO_2 e**	**Realistic level of takeup of action (%) by farmers / producers (based on existing evidence)**	**Delivery of actions through current programmes**	**Future mechanisms for potential delivery of actions**	**Crosscutting impacts of delivering actions**
Improve technical efficiency in lamb production – 10% CH_4 reduction	**95**	**1.6**	B & S sector less receptive to technical efficiency, harder to displace tradition	Delivery thru B & S development centres for Farming Connect	Farming Connect technical advice	Lower stock numbers = less diffuse pollution.
Feed to animal requirement , % saving	**85** Dairy (16.7%) **89** Beef & Sheep (5%)	**1.4** **1.5**	B & S sector more extensive and more resistant to change so likely reduction in emissions much smaller	Delivery thru Dairy, B & S development centres for Farming Connect	Farming Connect technical advice	Negative impact for biodiversity if no extentive stock grazing
Bioenergy						
Use of SRC / miscanthus to provide electricity –	Dairy – **35 – 56** Beef – **4 – 7** Sheep – **18 – 32**	**0.9 – 1.6**	High capital cost of CHP unit unrealistic for many farmers. Labour intensive if own coppice utilised, which will require change to farmers habits	No	Grant funding for capital costs plus Axis II scheme payment for woodland management	Positive impact on biodiversity from increase in managed woodlands. Planting / management of woodland will sequester carbon
Use of biodiesel for on-farm activity (OSR)	Dairy – **18 – 36** Beef – **2 – 5** Sheep – **12 – 25** Arable – **7.39 – 14.18**	**0.7 – 1.3**	Cost and availability main factor.	No	Currently no processing in Wales	Uses land in high demand for other activities
Use of biodiesel for on-farm activity (bioethanol)	Dairy – **12 – 25** Beef – **2 – 4** Sheep – **33 – 65**	**0.9 – 1.7**			Currently no processing in Wales	Uses land in high demand for other activities

Actions to mitigate emissions from agriculture (highest impact)	Total possible reduction in GWP for Wales (in kilotonnes of CO_2 e) if action taken up by all farmers / producers in each sector	% Reduction of total Wales GWP from Agriculture (2005) – 6020 Kt CO_2 e	Realistic level of takeup of action (%) by farmers / producers (based on existing evidence)	Delivery of actions through current programmes	Future mechanisms for potential delivery of actions	Crosscutting impacts of delivering actions
	Arable – **5 – 10**					
Anaerobic Digestion						
Methane recovery potential (around 28% of manures recoverable)	**110**	**1.8**	Very little potential on a single-farm basis due to very high capital costs and operational problems.	None on-farm.	Centralised AD plant feasibility study identified 3 areas in Wales with potential.	Ability to process other wastes (food etc) in addition to slurries.
Arable Sector						
Use of green manures before winter wheat crop	**7**	**0.1**	Would result in a 16% reduction in yield over the rotation cycle of 6 years. Reducing production unlikely to be considered by conventional arable farmers until fertiliser prices become unrealistic.	None except as part of organic conversion advice	Farming Connect technical advice	Reduction in diffuse pollution, reduced production / income, increased pressure on land availability
Clover Bicropping with winter wheat	**14**	**0.2**	Would result in a 40% reduction in yield. Reducing production unlikely to be considered by conventional arable farmers until fertiliser prices become unrealistic.	None except as part of organic conversion advice	Farming Connect technical advice	Reduction in diffuse pollution, reduced production / income, increased pressure on land availability

Actions to mitigate emissions from agriculture (highest impact)	Total possible reduction in GWP for Wales (in kilotonnes of CO_2 e) if action taken up by all farmers / producers in each sector	% Reduction of total Wales GWP from Agriculture (2005) – 6020 Kt CO_2 e	Realistic level of takeup of action (%) by farmers / producers (based on existing evidence)	Delivery of actions through current programmes	Future mechanisms for potential delivery of actions	Crosscutting impacts of delivering actions
Horticulture						
Use of SRC boilers for CHP in protected cropping	**7 – 9**	**0.1 – 0.13**	Impact limited – the 37ha of protected cropping is not all glasshouse but no data available to establish exact details	None	Grant funding for capital costs plus Axis II scheme payment for woodland management	Positive impact on biodiversity from increase in managed woodlands.
Peat alternatives	**If replaced totally with:** Coir - **1.24** Bark **- 1.26** Composted green waste - **1.32**	**0.02 max**	Low takeup due to mistrust of non-peat media by growers - peat mixes more reliable. Increase in demand for low-peat use produce may start to impact.	Accreditation schemes such as the European Eco-label (flower symbol)	Legislation against quantity of peat used in growing media mixes	Positive for biodiversity, reduction of landfill & other waste disposal

10.3 Table showing potential impacts at farm level of actions to mitigate emissions.

Mitigation Measure	Potential reduction in GHG emissions per year (t CO_2 equivalent)				
	Specialist dairy	**Hill beef / sheep**	**Lowland beef / sheep**	**Cropping**	**Organic Upland livestock**
Soils / sequestration					
Convert 10ha grassland / arable to woodland	146 – 165 (179 on organic soils)	146 – 165 (179 on organic soils)	146 – 165 (179 on organic soils)	146 – 165 (179 on organic soils)	146 – 165 (179 on organic soils)
Convert 5ha grassland to wetland	14 - 71	14 - 71	14 - 71	14 - 71	14 - 71
Nutrient / Resource Management					
Ensure fertilisers added only to crop requirements (5% reduction in N)	3.8	4.8	3.5	11.4	57.9 (no synthetic N applied at all in organic system)
Make full allowance of manure N supply (5% reduction in N)	3.8	4.8	3.5	11.4	N/A as no N used
Spread slurry / manure at appropriate times / conditions (10% reduction in N_2O)	7.7	9.7	7.1	22.7	N/A as no N used
Production					
Increase milk yield per cow	46	N/A	N/A	N/A	N/A
Decrease cow replacement age from 2.5 to 2 years	21.9	N/A	N/A	N/A	N/A
Reduce finishing period for beef cattle from 30 to 24months	4.8	18.8	19.5	N/A	30.7
Improve lambing % (10% reduction in sheep flock)	3.6	21.2	11.2	N/A	31.9
Feed to animal requirement	50.1	13.3	12.8	N/A	29.1
Cropping					
Use green manures before Winter Wheat	-	-	-	13.5 (0.45 t/ha)	-
Use intercropping techniques (wheat)	-	-	-	100 (1.25 t/ha)	-
Bioenergy[187]					
Use of Biomass for CHP	17.7 - 30.1	7 – 13.4	4.4 – 8.4	6.4 – 21.8	10.4 - 20
Use of Biofuels: Biodiesel - Ethanol -	 9.8 –20.1 8.1 – 16.4	 5 - 10.4 10.4 – 20.8	 3.1 – 6.3 5.8 –11.6	 37.4 –71.8	 26.2 – 50.2

[187] See table at Annex for calculations

Table 10.4 - typical farm examples for Wales (from Farm Business Survey Data)[188] (methane emissions lost to air at 6% of available energy fed for total herd / flock of each stock type shown in bold italic as t CO_2 equivalent)
(no. stock x glu x 86.9 KgCH_4 x 21/ 1000 = tCO_2 e)

10.5 Land / Stock	**Specialist dairy**	**Hill beef/sheep**	**Lowland beef/sheep**	**Cropping**	**Organic (Upland livestock)**
Area (ha)	101.2	156.6	93.3	200	140
Grassland (ha)	83.8	114.4	75.8		138
Crops (ha)	8.6	1.7	8.8	200 *(table 8.4 gives crop types & areas)*	1
Rough/woods, etc (ha)	8.8	40.5	8.8		
Effective area (ha)	94.5	127.8	88.7		136
Dairy Cattle	119 ***217.2***				
Suckler cows	1 ***1.8***	49 ***89.4***	26 ***47.5***		60 ***109.5***
Other cattle	90 ***67.89*** dairy replacements, 22 ***24.1*** beef	86 ***94.2***	89 ***97.45***		140 ***153.29***
Breeding sheep	124	713	351		700
Other sheep	75	449	261		1050
Emission from sheep flock	***36.3***	***81.9***	***111.7***		***319.4***
Stocking Rate (glu/ha)	2.15	1.18	1.35		0.80

[188] Farm Business Survey 2007

Annexes

Annex I

Table 5.2 - Shows the CO_2 emissions to air from the production of common fertiliser types.[189]

Item	% of each fertiliser type used in England & Wales (where known)	Reference Unit	Primary Energy used, MJ	GWP_{100}, kg CO_2 Equiv	CO_2 (total), to air, kg
Ammonium Nitrate (AN) as N	37	1 kg N as N	41.0	7.2	2.7
Urea (UN) as N	5.6	1 kg N as N	49.2	3.5	3.3
Calcium Ammonium Nitrate (CAN) as N	0.4	1 kg N as N	42.8	7.4	2.8
Ammonium Sulphate (AS) as N		1 kg N as N	42.4	3.0	2.8
Mean N fertiliser for grassland as N		1 kg N as N	41.9	7	3
Triple SuperPhosphate as P	1.2	1 kg P as P	18.6	1.3	1.3
Single SuperPhosphate as P	0.2	1 kg P as P	12.7	0.8	0.8
Rock P from 25% P2O5 Tunisian		1 kg P as P	15.3	1.1	1.1
Mean P fertiliser for grassland as P		1 kg P as P	18.5	1.3	1.3
K fertiliser (Muriate of potash - KCl)		1 kg K as K	5.7	0.5	0.5
Rock K		1 kg K as K	14.5	0.9	0.8
Gypsum as S (quarried)		1 kg S as S	5.5	0.3	0.3
Gypsum as S from FDG		1 kg S as S	1.9	0.1	0.1
Gypsum as S (Mixed)		1 kg S as S	3.7	0.2	0.2
Limestone as rock		1 kg product	0.9	0.06	0.06
Limestone as CaO		1 kg CaO	1.6	0.11	0.10
Limestone as Ca		1 kg Ca	2.3	0.2	0.1
Total for Burnt Lime (or chalk) as 90% CaO product		1 kg product	6.0	0.2	0.2
Burnt Lime (or chalk) as CaO		1 kg CaO	6.1	0.16	0.15
Burnt Lime (or chalk) as Ca		1 kg Ca	8.5	0.2	0.2
Weighted Lime usage as product		1 kg product	3.4	0.2	0.2
Weighted Lime usage as CaO		1 kg CaO	2.3	0.1	0.1

[189] Williams, AG; Audsley, E and Sandars, DL (2006), Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main report, Defra research project IS0205. Bedford: Cranfield University and Defra.

Weighted Lime usage as Ca		1 kg Ca	3.2	0.2	0.2
Imported compost (total FW basis)		1 t	80.3	5.1	4.9
Compost-N		1 Kg	8.6	0.5	0.5
Compost-P		1 kg	8.6	0.5	0.5
Compost-K		1 kg	8.6	0.5	0.5
Compost-S		kg	8.6	0.5	0.5

Annex 2

"Typical" farm types in Wales, Specialist dairy, hill beef and sheep and lowland beef and sheep taken from FBS survey data, 2006/07. Organic data is from organic farms (n=17) survey data from 2004/05.

	Specialist dairy	Hill beef/sheep	Lowland beef/sheep	Cropping *	Organic (Upland livestock)
Area (ha)	101.1	156.6	93.3	200	140
Grassland (ha)	83.8	114.4	75.8		138
Crops (ha)	8.6	1.7	8.8	200	1
Rough/woods, etc (ha)	8.8	40.5	8.8		
Effective area (ha)	94.5	127.8	88.7		136
Dairy Cattle	119				
Suckler cows	1	49	26		60
Other cattle	112	86	89		140
Breeding sheep	124	713	351		700
Other sheep	75	449	261		1050
Stocking Rate (glu/ha)	2.15	1.18	1.35		0.80

Annex 3

Livestock Unit Calculator (ADAS booklet 2267)

	Number	Months on farm	LU	Total LUs
Dairy cow	264403	12	1.00	264403.00
Dairy youngstock 0 - 12 months	0	12	0.30	0.00
Dairy youngstock 12 - 24 months	83483	12	0.54	45080.82
Dairy youngstock 24 months +	58877	12	0.80	47101.60
Beef Cows (ex calf)	220745	12	0.75	165558.75
Bulls	9687	12	0.65	6296.55
Suckled calves 0 - 12 months	0	12	0.30	0.00
Calves from suckler herd 12 - 24 months	2564	12	0.54	1384.56
Cattle 24 months +	68269	12	0.80	54615.20

Other cattle 0 - 12 months	285776	12	0.30	85732.80
Other cattle 12 - 24 months	221222	12	0.54	119459.88
Other cattle 24 months +	25739	12	0.80	20591.20
Total cattle LUs	1240765			810224.36
Sheep				
Light ewes (40 kg)	0	12	0.07	0.00
Medium ewes (50 kg)	4116433	12	0.08	329314.64
Medium ewes (60 kg)	0	12	0.09	0.00
Heavy ewes (70 kg)	0	12	0.10	0.00
Very Heavy ewes (80 kg)	0	12	0.11	0.00
Rams	103107	12	0.08	8248.56
Lambs				
Birth to store	4557287	9	0.04	136718.61
Birth to fat	0	12	0.04	0.00
Birth to hogget - replacements	615778	12	0.07	43104.46
Sheep over 1 year	117779	12	0.07	8244.53
Total sheep LUs	9510384			525630.80
Total livestock units				1335855.16

Annex 4

Calculation of methane from ruminant emissions.

Daily CH_4 emission = [GE * Ym] / 55.65 MJ/kg CH_4……………(1)
[CH_4/head/day]

Where:
GE = gross energy intake (MJ/head/day)
Ym = fraction of GE converted to CH_4

A “Livestock unit” is defined as 48 GJ ME/annum = 131.5 MJ ME/day.

If the average ruminant diet in Wales is 11.0 MJ/kg DM,
and the average GE of ruminant feeds is 18.5 MJ/kg,
then daily GE intake = 18.5/11.0 * 131.5 = 220.9 MJ GE/LU/day

If an average of 6% GE is converted to CH_4, then:

$\frac{220.9 * 0.06}{55.65} = \frac{13.254}{55.65}$ **= 0.238 kg CH_4 / LU / day or 86.9 kg CH_4 / LU / year**

See attached spreadsheet.

From 2006 Welsh Agricultural Statistics, for year 2005, Welsh ruminant livestock was equivalent to 1,335,855 livestock units, (48GJ ME /unit)

1,335,855 * 86.9 kg CH_4 = 116,086 t CH_4 / annum

Equivalent to 116,086 * 21 = **2.438 Mt CO_2 / annum**

From the inventory: ('000 t CO_2 equivalent)

4A1,	dairy cattle, enteric	575
	other cattle, enteric	892.9
4A3	sheep, enteric	966.6
		2434.5 = **2.434 Mt CO_2 / annum**

Equation (1) from: http://www.epa.gov/ttn/chief/conference/ei12/green/mangino.pdf

Annex 5

% Measures for energy & carbon savings in protected horticulture (5207 GWh total energy use for the 1792 ha protected crops in the Uk), includingl payback period and potential barriers to adoption of these measures[190],

Energy-saving boiler measure	Potential energy savings	C savings (kilo-tonnes)	Payback period (years)	Barriers to take-up
Monitoring and benchmarking	520 GWh 10%	30	0-2	Sub-metering needed. Communal action needed.
Improved greenhouse cladding and reduced air leakage	230 GWh 4%	13	2-5	Investment in new glasshouses
Decentralised boiler plant	230 GWh 4%	13	2-5	High capital cost. Cultural resistance.
Improved design (including flue gas condensers)	230 GWh 4%	13	2-5	High capital cost. Only practical with gas, and where low grade heat can be utilised.
Thermal screens	240 GWh 5%	14	2-5	High capital cost. Cultural resistance in edibles sector.
Correct insulation and sizing of thermal stores	240 GWh 5%	14	2-5	
Temperature integration and climate control	800 GWh 15%	45	2-5	Technology transfer needed. Worry about losing control! Research gaps.
CHP installation (fossil fuel)	1,050 GWh 20%	60	5-10	High capital cost. Electricity requirements have to be high or there is export potential (local infrastructure needed).
High efficiency lighting	15 GWh 0.2%	0.7	2-5	High capital cost. Research gaps.
Improved motive power application	30 GWh 0.6%	1.4	0-2	Research gaps. Technology transfer needed.
In Comparision:				
Use of SRC CHP boiler for all of Wales 37ha of protected crops	80 – 91%	7.4 – 8.4	Not calculated	High capital cost. New technology so tech transfer needed. Cultural resistance

[190] Warwick HRI 2005

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