CLIMATE CHANGE AND SCOTTISH AGRICULTURE: REPORT AND RECOMMENDATIONS OF THE AGRICULTURE AND CLIMATE CHANGE STAKEHOLDER GROUP (ACCSG)

Drawing on a range of evidence, this report summarises the ACCSG's findings regarding the implications of climate change for Scottish agriculture and offers a number of recommendations for further action. Responsibility for taking these forward rests jointly with the Scottish Government and its agencies, but also the industry and other stakeholder bodies. It is their responsibility to collectively rise to the challenge.

SUMMARY OF RECOMMENDATIONS

A RESEARCH AND DEVELOPMENT NEEDS

A1. On-going developments in UK-level scenarios, and projections for climate change must be monitored. Existing research to interpret these within and across Scotland must be updated and extended to more sites.

A2. The methodological basis for estimating and reporting agricultural emissions must be improved to more accurately reflect the baseline and on-going sectoral position. Failure to do so risks misdirecting mitigation efforts by misrepresenting the volume and pattern of emissions and industry attempts to adjust.

A3. Further research must be conducted within the Scottish context to identify and cost both adaptation and mitigation options, to assess their individual practicalities and their relative cost-effectiveness rankings.

B POLICY DESIGN NEEDS

B1. Better integration between currently separate policy themes such as agriculture, forestry, deer management, flooding and biodiversity – all of which are linked to land use and require some degree of spatial co-ordination and co-operation across different parcels of land and therefore different farms – must be pursued.

B2. Recent experience of incentive schemes under Pillar II of the CAP and of regulatory controls under (especially) Nitrogen Vulnerable Zones or the Water Framework Directive must be used as a guide to how best to encourage Scottish land managers to respond to climate change.

B3. The scope for modifying Scotland Rural Development Programme measures and funding and/or enhancing cross-compliance to better control net emissions must be explored. **For the longer-term, attention needs to be paid to designing market mechanisms to promote mitigation**.

C INDUSTRY ACTION NEEDS

C1. Farmers and other land managers need to be aware of the potential positive and negative influences of climate change and adjust their business practices accordingly.

C2. Farmers and other land managers need to contribute to mitigation of the anthropogenic drivers of climate change and to helping wider society adapt to climate change

C3. Representative industry bodies at all stages of the supply-chain need to acknowledge the challenges and opportunities of climate change – including sectoral responsibilities - and then to help shape and guide collective and proportionate responses in collaboration with government, research institutions and other stakeholders.

C4. Some of the most important measures that land managers can take to mitigate climate change or adapt to its impact on the environment are likely to be more effective if they are taken collaboratively, acting together at the landscape or catchment scale.

D COMMUNICATION NEEDS

D1. Consistent and key messages must be agreed and methods for communicating them to different target audiences identified. **This should be informed by professional communication experts.**

D2. Established communication channels - such as codes of practice, newsletters, trade-shows and seminars - should be exploited as communication mechanisms for general information.

D3. More focussed, bespoke, interactive, facilitated communication approaches require to be adopted. A number of recommendations that have been put forward for adaptation and mitigation of climate change will require not only communication and advice using conventional approaches but also a more interactive approach. Such an approach needs to engage farmers in determining solutions that are relevant to their operations and for which they take responsibility and ownership.

I. Introduction

1. The Agriculture and Climate Change Stakeholder Group (ACCSG) was formed in November 2006 to consider the implications of climate change for Scottish agriculture (see Annex A for remit). The Group comprises representatives from several stakeholder bodies (see Annex B) and has met 12 times, with its deliberations aided by several expert presentations(see Annex C), a commissioned review[1] and discussions at a policy seminar held in Peebles. It also benefited from liaison with the Rural Climate Change Forum (RCCF)[2] – a group with a similar remit reporting to DEFRA.

2. This report summarises ACCSG's findings and offers a number of recommendations for further action. The next section presents the context within which ACCSG operated. Sections III and IV report the likely nature of climate change in Scotland, its effect on agriculture and possible adaptations. Sections V and VI report the contribution of Scottish agriculture to anthropogenic greenhouse gas emissions and how this might be mitigated. Section VII considers some economic aspects of mitigation and how it might be encouraged. Section VIII concludes with four firm sets of recommendations for further action.

3. Although presented under a number of discrete headings, linkages can and should be drawn between all of the Sections. Indeed, although ACCSG's remit related primarily to agriculture, it rapidly became apparent that climate change spans different aspects of land use and its associated public goods or co-benefits, and that none can be viewed in isolation. Consequently a recurring theme of this report is the need for greater consistency and co-ordination across different land use policies, such as agriculture, forestry, flooding, biodiversity and landscape but also food and energy security and rural development.

4. In addition, another key theme is the need to consider the trade-offs involved in adjusting to the challenges of climate change, whether through adaptation to cope with its consequences or mitigation to reduce pressure for further climate change. That is, most adjustments will entail additional costs in the form of extra effort, income forgone or the loss of some public goods. Since different forms of adjustment will incur different levels of such costs, cost-effectiveness should guide the order in which adjustments are prioritised not only within agriculture but also across other sectors of the economy: all other things being equal, lower cost adjustments should be pursued before higher cost ones. Moreover, the costs of any adjustment also need to be viewed against the benefits achieved, with only those adjustments delivering benefits in excess of costs actually justifying implementation. Within these constraints, a number of agricultural adjustments may be readily identified and are summarised.

---

[1] See www.scotland.gov.uk/topics/agriculture/agricultural-policy/17289/change

[2] See http://www.defra.gov.uk/environment/climatechange/uk/agriculture/rccf/index.htm

II. Context

5. In a Forward Strategy for Scottish Agriculture: Next Steps, published in March 2006, it was recognised that there was mounting evidence about the prospect of significant climate change. Noting that the agriculture industry could make a contribution towards mitigating climate change, and that also there were potential business opportunities, it recommended that a stakeholder group should be established to evaluate and monitor agriculture's response to climate change, through mitigation and adaptation.

6. In the 18 months since the ACCSG started its work, the development of global and national scientific research and policy on climate change has been rapid.

7. On 12 December 2007, at the United Nations Climate Change Conference in Bali, Indonesia, UN Secretary General Ban Ki Moon stated that ` The time for equivocation is over. The science is clear. Climate change is happening. The impact is real. The time to act is now.`

8. The Intergovernmental Panel on Climate Change (IPCC) tells us that the impact of climate change - the extinction of species, damage in our cities and high death tolls from severe weather events and a dramatic reduction in the production of food in parts of the world - will be difficult to mitigate, but not impossible.

9. The Stern Review published in October 2006 considered the economics of climate change. The Review states that if the world fails to stabilise emissions in a relatively short space of time, it could lead to problems on a scale similar to those associated with the Great Wars and the economic depression of the first half of the twentieth century. A general message is that early action will cost the World`s economies less in the long run than putting off such action. It suggested that developed economies should reasonably sacrifice just over 1% of current GDP to mitigation activities now, to avoid higher GDP losses in the future. As a rough approximation, this currently equates to around £900 million per year in Scotland.

10. The UK Climate Impacts Programme (UKCIP) has formulated scenarios of possible future climate change, dependent on predicted future global greenhouse gas emissions.

11. On 29 January 2008 the Scottish Government launched a consultation on its proposed Scottish Climate Change Bill which sets out a target to reduce emissions by 80% by 2050. It points out that the debate has clearly shifted in recent years from whether climate change is happening to what is causing it and what we need to do about it. It suggests that climate change presents major challenges for Scotland`s land using industries, but that a well planned and coordinated adaptation response will minimise the negative impacts and highlight potential opportunities. The consultation focuses on the long-term framework that is required for monitoring and reporting on progress. The Spending Review also committed the Government to reducing emissions in the period to 2011 in line with the pathway towards the longer term target; and preparing a programme of actions across all portfolios to deliver both the 2011 and 2050 targets.

12. The Scottish Climate Change Bill has been brought forward to create mandatory climate change targets to:-

- Drive decisions in government and business;
- Create and enable new means of reducing emissions and adapting to climate change;
- Play our part in global action on climate change; and
- Provide a strong example to other countries showing what can be done.

The intention is to present a strategic overview of policies that will contribute to the 2050 target at the time the Bill is introduced into Parliament in autumn 2008.

13. Work is currently underway to introduce a system to force down emissions from government spend over time, in line with the 80% target. The carbon assessment of policies and projects is a prerequisite for compliance with such mechanisms and the Scottish Government has committed to having in place a carbon assessment tool by 2009-10, providing necessary incentives to seek out lower carbon means of delivery across all Government. However a decision has still to be taken on whether the 80% target will apply to CO_2 emissions alone or to the basket of greenhouse gases (GHG) covered by the Kyoto Protocol.

14. The Scottish Government is well placed to influence many of the policy areas central to a strong mitigation and adaptation response in Scotland, and is currently developing a Scottish adaptation strategy to identify priority adaptation action required in Scotland and to clarify roles and responsibilities in achieving this action.

15. The Discussion Paper, the Future of Food in Scotland, launched by the Scottish Government in January 2008, set out a vision for food in Scotland where a greener Scotland would result from reducing the environmental impact of food and drink. On-going discussion about "food miles" and promotion of local food will be part of the overall debate.

16. In March 2008, a consultation on Forestry Commission Scotland`s Draft Climate Change Action Plan 2008-2010 was launched.
www.forestry.gov.uk/forestry/infd-7bqlg8

III. Climate Change in Scotland

17. Whilst the existence of climate change is widely accepted, there is still some uncertainty in the pace, pattern and magnitude of this change. This is reflected in the range of official scenarios used for future projections, with “low emission” scenarios generating less dramatic change than “high emission” scenarios. Nevertheless, it is expected that, on average over the course of this century, annual temperatures will rise whilst precipitation will increase in winter but decrease in summer. In addition, the frequency and intensity of extreme events such as storms or droughts may increase, possibly sooner than changes to average conditions.

18. As a result, most areas in Scotland are likely to experience a longer agricultural growing season. Improved crop and grass growth will lead to new enterprises becoming viable as their biological limit extends northwards. Conversely, the viability of some existing enterprises will reduce due to, for example, increased soil moisture deficits or heat stress. Equally, some existing and new weeds, pests and diseases will become more common in warmer and wetter conditions. Within this, there will be regional variation across Scotland – as with current conditions from north to south and west to east.

IV. Adapting to Climate Change

19. The impact of climate change depends jointly upon the nature of the change itself and reactions to it. Most analysis suggests that – given adoption of appropriate farming practices, new technologies and policies - agriculture in higher latitude countries such as Scotland can adapt to climate change and benefit from new biological and market opportunities. In many cases, farm-level adaptation will arise autonomously as individual farmers continue to make within-year and longer-term decisions with respect to, for example, timing of field operations, choice of cultivars and enterprises, and financial, marketing and risk management arrangements. However, adaptation will also be influenced by other factors such as CAP reform, global production and trade, and technological change – many of which present more immediate pressures than climate change.

20. The following Tables 1-3 summarise possible adaptation responses at the farm-level for both the short and longer-term. The categories are drawn from relevant literature but also feedback from participants at the Peebles seminar. Particular farm-level examples mentioned by practitioners at that event include adopting crop cultivars and livestock breeds with resilience to heat and water stress – including those developed using GM technologies – plus new enterprises such as maize for fodder, or root crops and soft fruit as well as production systems of different intensities and configurations based on sustainability principles.

Table 1 **Possible adaptation responses to agricultural climate change influences:** **Autonomous, within-season (farm-level)**
Timing of ploughing/sowing/harvesting crops
Timing of turning-out/gathering in livestock
Timing and volume of fertiliser/manure/chemical/irrigation applications
Duration and intensity of livestock grazing
Timing and number of silage/hay cuts
Volume of bought-in livestock feed
Timing of product marketing
Use of financial risk management techniques

Table 2 **Possible adaptation responses to agricultural climate change influences :** **Autonomous, longer-term (farm-level)**
Choice of crop cultivar
Choice of livestock breed
Investment in irrigation equipment
Investment in water storage facilities
Investment in drainage systems
Investment in livestock housing
Location of existing enterprises across farm
Mix of enterprises
Type of land-use system
Short Rotation Coppice (SRC) and Short Rotation Forestry (SRF) for Energy
Woodland management for water quality, flood alleviation (downstream), habitat connectivity, ammonia capture, and reduction in fertiliser requirements
Business structure and use of contracting/co-operation/supply-chain integration
Diversification of on-farm activities
Diversification of off-farm investments and employment

21. Achieving farm-level adaptation may need various forms of on-going public support, as summarised in the following Table 3.

Table 3 **Possible adaptation responses to agricultural climate change influences :** **Planned, on – going but longer term (institutional level)**
Information and advisory support for farm-level adaptation measures
Support for weather/climate and pest/disease awareness and monitoring
Research and Development into new crop cultivars and livestock breeds
Co-benefits/systems perspective of agricultural resources to support non-farm adaptation

22. This may require some adaptation in the way that policies are designed and implemented across different branches of government. In addition, beyond its own interests, agriculture and land use will also have a role to play in helping wider society to adapt to climate change. For example, some farmland will offer opportunities to respond to flood and drought risks through woodland and wetland management for water control (including pursuit of Good Agricultural and Environmental Condition, and the Water Framework Directive's Good Ecological Condition). Equally, appropriate land management to enhance habitat connectivity may alleviate climate change pressure on biodiversity. This will require improved co-ordination across different areas of current land use policy – which again implies some institutional adaptation.

V. <u>Agricultural emissions</u>

23. Although farming will be affected by climate change, agricultural activities are acknowledged as a significant source of greenhouse gas (GHG) emissions and therefore a contributor to climate change. In particular: carbon dioxide (CO_2) is released by cultivation disturbance of organic carbon held in soils and vegetation and through the use of fossil fuel to power machinery and buildings; methane (CH_4) is generated by livestock digestion and from manure; and nitrous oxide (N_2O) is associated with applications of fertiliser and manure to soil. Methane has around 20 times the greenhouse effect of carbon dioxide, nitrous oxide around 300 times. For ease of interpretation, different GHGs are usually expressed in the common unit of carbon dioxide equivalents (CO_2e). Details on estimated emissions by selected sources and sinks associated with Scottish agriculture can be found at Annex F.

24. However, both scientific uncertainty and a lack of appropriate data hinder precise measurement of emissions from Scottish agriculture. Some spatial variation in some aspects of environmental conditions and management practices can be taken into account in broad types of land use. But, for example, variation in soils underlying grassland can cause emission differences unaccounted for within that land use category and the inventory methodologies are not responsive to some management practices (eg livestock diet) at all. This means that reported estimates may misrepresent the magnitude and pattern of emissions. In addition, the categorisation of emission sources for reporting purposes can mask the aggregate level of sectoral emissions.

25. The recent significant reductions in GHG emissions from agriculture can largely be attributed to reductions in livestock numbers. The economic performance of livestock agriculture in Scotland indicates that continuing downward adjustments in livestock numbers and greater overall production efficiencies within the industry are likely to take place. While this trend will result in a reduction in GHG emissions, there is nevertheless also a need to retain capacity to meet the requirements of home demand for livestock products so that possible net additional emissions arising from the production and transport of food from less environmentally efficient areas of the world are avoided. On the basis that market conditions might be expected to reflect society`s relative demand for food products as against the value it places on the impact of climate change, there is not a robust case for any unilateral policy intervention that attempts to control stock numbers.

26. Crop and livestock production remain core activities of Scottish agriculture. Improved efficiency and the use of practical, cost effective techniques to reduce operational emissions as described below must be encouraged. However there will be a limit to what can be achieved by agriculture as long as there is a continued requirement to produce food as close to the source of consumption as is possible. In terms of GHG emissions this is consistent with present strategies to reduce emissions arising from the food supply chain. Thus, in setting targets for reduced emissions from agriculture they need to be considered in relation to the overall expected food supplies that Scottish agriculture will be expected to achieve arising from its developing first National Food Policy.

27. These problems are apparent in the official reporting mechanism for Scottish emissions within the UK - the “National Inventory”. This uses a relatively simplistic approach to estimating most agricultural emissions, neglecting the known heterogeneity of farming systems and the potential for management to affect emissions. In addition, agricultural emissions are reported across several different categories, only one of which is labelled explicitly as “Agriculture”. The latter gives a headline figure of agriculture contributing around 13% of Scottish emissions, whereas summing across identifiable farming activities from different categories gives a figure of around 25%. On the other hand, the benefit of the National Inventory is that it provides a consistent means of measuring emissions at international level, in accordance with reporting requirements under the Kyoto Protocol.

28. Specifically, fossil fuel usage on-farm for heating and lighting plus mechanical operations is presented under the “Energy” category, but represents about 5% of total farming emissions. More significantly, carbon released from the conversion of grassland to arable crops is reported under the “Land Use, Land Use Change and Forestry” category yet represents about 45% of farming emissions. The remainder, reported explicitly under “Agriculture” refers mainly to nitrous oxide released from soils (26%) and methane from livestock digestion and manure (20%). Alternative measurement methodologies – including Life Cycle Assessment (LCA) – categories and baselines give different figures.

VI. Agricultural Mitigation

29. Whichever methodology is used to estimate its emissions, and regardless of which emission category individual farming activities are reported under, agriculture will be expected to play a role in helping Scotland meet ambitious targets for reducing overall GHG emissions. From a technical perspective, there are many potential options for achieving this and these may be grouped into three broad categories – brief summarised examples of which are given in Tables 4 -21 below, drawing on the literature and a number of expert presentations given to ACCSG. A fuller explanation of what recent literature has estimated as the cost effectiveness of such approaches is to be found in the Pareto report. www.scotland.gov.uk/topics/agriculture/agricultural-policy/17289/change.

Reducing emissions

30. First, the most direct approach to using agriculture to mitigate GHG emissions is to reduce the level of emissions arising from farming activities themselves. This can be approached by improving the efficiency of production (to emit less CO_2e per unit of output) and/or by lowering the volume of production. Techniques for the former range from adoption of current best management practices such as nutrient budgeting and saving energy on-farm, to adoption of different systems for livestock rearing and manure handling

Table 4 **Adoption and maintenance of modern machinery and buildings**
Newer designs for machinery such as tractors, grain dryers and milking parlour equipment and for buildings – particularly heated/lit sheds for intensive livestock – are generally more **energy efficient** than older designs. Hence replacement of older capital items with modern designs can reduce fuel and energy usage, thereby avoiding some emissions. Regardless of design vintage, regular maintenance and energy-conscious usage can also avoid some emissions. Energy efficiency is generally a **win –win** mitigation method since reductions in emissions are associated with reduced energy usage that also saves private costs, even if capital investments are required.

Table 5: **Improved utilisation of nutrients for plant growth**
Matching applications of fertilisers and manure/slurry to plant growth conditions to reduce nutrient wastage and thus N_2O emissions. Technically feasible and **generally a cost-saving exercise** for producers, but dependent on wider adoption of best practice. Linked to farmer behaviour and attitudes in response to benchmarking-type information and advice regarding the timing, magnitude, mode and spatial precision of applications plus possible barriers to uptake and maintenance of modern equipment. Research is needed to improve water and nutrient acquisition by roots and the efficiency of their use in plants. **Possible positive co-benefit effects**, largely in form of reduced water pollution.

Table 6 **Minimising Soil Exposure**
Bare cultivated soil is prone to erosion and nutrient leaching. Timely cultivations and use of \`catch\` and \`cover\` crops can be used to limit extended periods of bare soil. Feasible but may involve significant change to management practice and lead to seasonal workload pressures. Possible co-benefits for biodiversity from over-wintering stubbles and green manures as well as for water quality.

Table 7 **Reduced tillage**
Field operations, especially ploughing, disturb soil organic carbon. Avoiding such disturbance through reduced tillage techniques can thus save some CO_2 emissions. Technically feasible, although requires some adjustment to management practices and possible capital expenditure on new equipment. Effect on co-benefits depends on mode of uptake: reduced tillage can sometimes lead to increased use of chemicals to control pest/weed/nutrient levels plus increased N_2O emissions.

Table 8 **Improved manure and slurry storage**
Partially linked to improved utilisation of nutrients by facilitating greater flexibility in the timing of manure/slurry utilisation, but also aimed at reducing CH_4 emissions by seeking to reduce the moist surface area of manure/slurry exposed to air. Technically feasible through (e.g.) covered storage facilities or reducing wetness by mixing with drier material but possibly inhibited by capital costs of improved facilities. Relative attractiveness may increase with regulatory (e.g. NVZ) pressure but also rising fertiliser prices making recycling of on-farm resources competitive. Possible positive co-benefit effects, largely in form of reduced water pollution.

Table 9 **Reduced roughage intake/improved dietary controls**
Greater usage of concentrates and control over livestock diets can reduce N_2O and CH_4 emissions. Technically easier for housed livestock, making it perhaps more compatible with dairying than current beef or sheep systems. Contingent on relative feed prices and capital costs of alternative systems. Intensive beef production perhaps at odds with current marketing image of extensive Scotch beef. Possible negative effects on habitats from loss of livestock grazing and possible local pollutant risks from housed systems - and from additional feed production, which may emit other GHGs and cancel any savings.

Table 10 **Dietary supplements**
Rumen efficiency can be enhanced through the use of various feed additives or other stimulants. Many are still under technical development, but others are already available and can deliver CH_4 savings. Perhaps less dependent on housing than other dietary management options, but still more suited to relatively intensive systems due to need for closer management, with possible negative effect on grazing-dependent habitats and biodiversity.

Table 11 **Adoption of larger, faster maturing breeds**
Shifting to larger, faster maturing breeds – both existing ones and future ones arising from continued breeding programmes – would reduce emissions per kilogram of meat or milk. Technically feasible, but compatibility with traditional, extensive livestock rearing in hills and uplands in terms of both practical husbandry and marketing image is questionable.

31. In addition to lowering emissions per unit of agricultural output, overall emissions could also be reduced by lowering either the volume of output and/or changing its composition. For example, keeping fewer livestock or switching from ruminant to non-ruminant species would lower methane emissions significantly. However, the net effect of such domestic production responses on global GHG emissions would depend on how consumption of (especially) red meat and dairy products would alter. That is, in the absence of changes in consumption behaviour, livestock and methane production could simply shift to a different (i.e. overseas) location and be imported back to here. Such “leakage” has already been noted in the context of manufactured goods no longer produced domestically but still consumed in the UK. This may allow domestic emission targets to be met, without necessarily reducing emissions at the global level. Furthermore, downward adjustments in domestic livestock numbers, particularly sheep and cattle in the hills and uplands, may result in other non domesticated wild herbivores, such as deer, increasing in number. Unless, therefore, wild deer populations are strictly controlled there is every possibility that any reductions in GHG emissions from a reduction in livestock production could be reduced significantly by the GHG emissions arising from increased numbers of deer.

Table 12 **Fewer Livestock**
Destocking is technically straightforward and a direct method of avoiding domestic emissions of (especially) methane. Indeed, under current estimation methodologies for national GHG inventories, this is the only way of achieving significant reductions in headline levels of domestic emission levels. However, such a radical approach to mitigation has implications beyond GHG emissions through commodity production links to up and downstream sectors, to other environmental public goods and to wider rural economy and community vitality. That is, simply focusing on GHG mitigation may risk damaging significant co-benefits, although they might theoretically be delivered by other means.

Table 13 **Switch to non ruminant livestock**
Substituting, for example, monogastric pig and poultry production for ruminant sheep and beef is technical feasible, albeit with some significant implications for capital expenditure on farm and for supply-chain infrastructure. However, commercial viability is highly contingent on relative prices of different livestock products and consumer responses to changing availability of beef and lamb vs. pig and poultry. In addition, a radical shift in agricultural production patterns has implications for environmental public goods associated with land use and implications for agricultural supply chain adjustments and for rural economy and community vitality.

Displacing emissions

32. Second, utilising alternative sources of energy as a substitute for fossil fuel represents a potential means of displacing some GHG emissions from within agriculture and/or across the wider economy. In addition to possibilities for wind or hydropower at specific sites, agricultural land more generally could be used to produce bioenergy. In particular, crops, farm waste, and woody products can be used to produce biofuels, biogas and biomass. The net GHG displacement depends on how the bioenergy is produced – this can itself generate GHGs, reducing the overall savings – and its relative energy content.

Table 14 Biofuels
Liquid bioethanol from (e.g.) wheat or biodiesel from (e.g.) oil seed rape, as direct substitute for petrol and mineral diesel. Relatively straightforward to grow and therefore familiar to farmers, but highly dependent on policy support and processing capacity infrastructure. Domestic and EU legislation may drive market demand, but different crops yield vastly different energy and carbon outputs and imported raw materials may dominate. Possible negative co-benefits (abroad) of imported raw materials, but also domestic effects on land use patterns and input usage e.g. ploughing-up of set-aside, plus knock-on effects of higher commodity prices. So-called “second generation” biofuels may offer greater net benefits.

Table 15 Biomass
Biomass: Direct combustion of biological material, either to generate heat and/or electricity. Typically involving timber products, most often in the form of short rotation coppice (SRC), or short rotation forestry (SRF), but other more traditional woodland management systems and other types of material can be used. Most effective if used in some form of combined heat and power installation, either for on-farm or nearby usage – although capital outlay and planning controls may inhibit this. Highly dependent on policy support for capital investment and on-going price of “green” energy. Change of land use can change biodiversity and landscapes in some circumstances and the removal of field residues, such as straw, may compromise low input systems such as organic farming.

Table 16 **Biogas**
Collection of CH_4 from housed livestock and (more usually) anaerobic digestion of waste products, for generation of heat and/or electricity. High initial capital costs and on-going issues of scale efficiency for size of plant and throughput – the latter may necessitate access to additional material, either off-farm waste and/or specifically-grown on-farm material. As with biomass, highly dependent on policy support for investment and value of "green energy", but also permitted usage of the digestate (i.e. compost) by-product.

Table 17 **Hydro Power**
Converting potential energy stored in water at height, or from rivers (high and low head systems respectively) increasing in potential as improvements in small turbine and generator technology occur. Capital cost generally high, although very site specific. Assistance from Government support schemes. Economic viability assisted by market liberalisation and increase in bulk price of energy. Possible difficulties include availability and cost of grid connection and responding to planning and environmental issues.

Table 18 **Wind Power**
Steady improvements in technology in recent years. A wide variety of turbines available. Particularly attractive for farms with substantial on farm energy demands, with surplus sold to the grid. Small turbines can be used where no grid supply. Possible government support. Capital costs significant. Potential returns very site specific dependent on wind speeds and proximity to grid. Visual impacts, along with noise and vibration may cause planning issues and the need for local consultation.

Enhancing removals

33. Third, soils and standing vegetation have the ability to capture and store (sequester) atmospheric carbon and, if left undisturbed, this could off-set emissions elsewhere. Indeed, land-based sequestration is estimated to already offset around 4.5 Mt CO_2e per year within Scotland, and a proportion of this is attributable to agricultural land. Possible approaches to enhancing removals include accelerated woodland creation and restoration of degraded soils. In addition, existing stores – particularly in peat rich soils and standing trees – need to be protected. As with other mitigation options, sequestration and storage protection implies changes in land use and highlights linkages between different sectors, such as agriculture, forestry and upland or wetland management.

Table 19 **Land idling (e.g. set aside)**
Field operations disturb soil organic carbon, both within and across seasons. Removing land from production, either temporarily or permanently (as with set-aside) avoids such disturbance and thus offers some CO_2 savings. This may have positive effects on habitat and biodiversity co-benefits. Technically feasible, but contingent on existing farming systems (e.g. rotational patterns) and value of output forgone through idling. A less permanent reduction in cultivated area than (e.g.) afforestation or wetland restoration.

Table 20 **Prescriptive restorative management**
Many agricultural soils, both peat-based or mineral-based, contain less organic carbon than their natural potential. Applying appropriate positive management – such as reducing drainage or retaining organic residues, potentially with Scotland Rural Development Programme support – to such soils may have positive effects on habitat and biodiversity and offers the possibility of co- benefits of restoring their capacity to capture and store carbon, thereby enhancing removals. This is technically feasible, but possibly constrained by cost of applying prescriptions to some existing farming systems both in terms of additional effort and lost output.

Table 21 **Woodland creation**
Tree planting offers an obvious means of sequestering atmospheric carbon in a durable form that remains in situ for decades and even on harvesting may still represent a carbon store. Rates of sequestration depend on tree species, site-specific growing conditions and management prescriptions, as do effects on co-benefits such as habitats, water quality and landscapes. As with other options, diversion of farmland may have knock-on effects for other commodity markets.

VII. Achieving mitigation

Cost-effectiveness

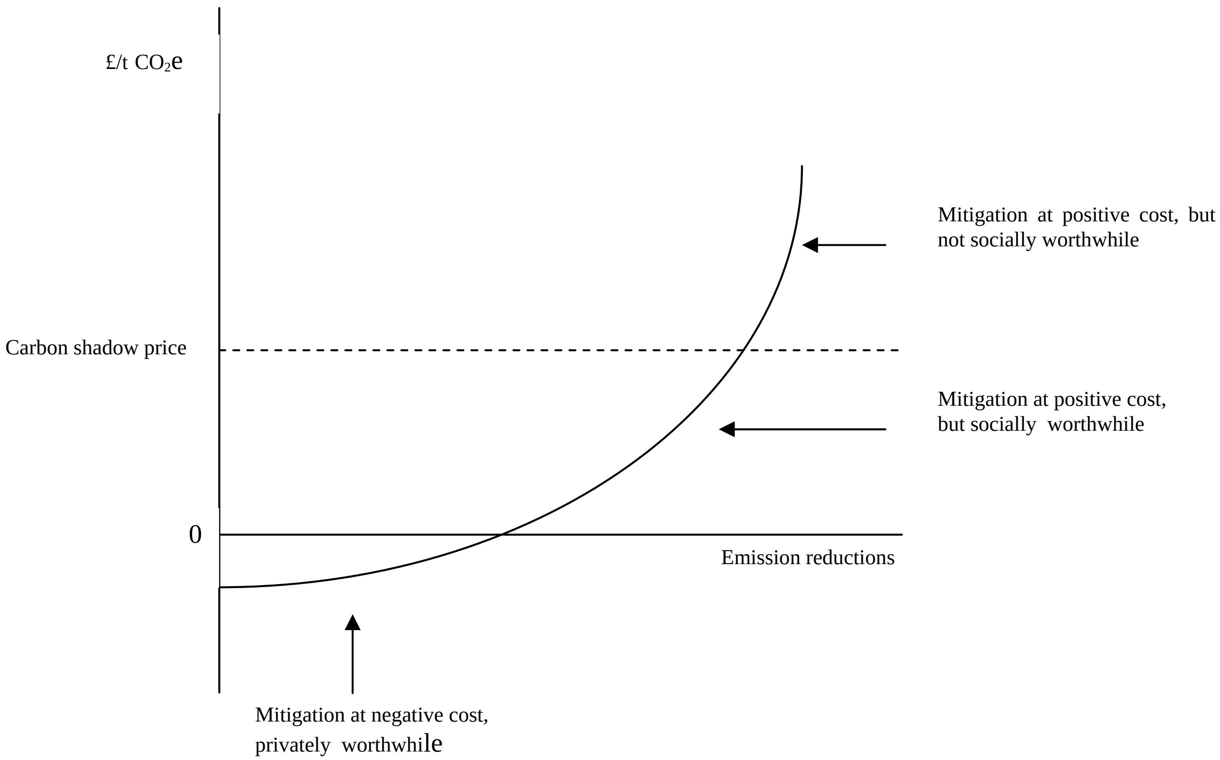
34. Although there are many different potential ways for agriculture to mitigate GHG emissions, not all of them are equally attractive. Whilst some are technically feasible now, others are not yet proven and require further research. Of those that are currently feasible from a technical perspective, some are more expensive to implement than others and, all other things being equal, lower cost options should be pursued before higher cost options.

35. Moreover, to justify adoption, the costs of any given mitigation option have to be less than the benefits it conveys. The latter include the value of damage avoided by reducing GHG emissions, referred to as the social cost or the shadow price of carbon. The impacts of these options on associated multifunctional ecosystem services also need to be taken into account (see Table 22 for an example).

36. Although subject to on-going academic debate and contingent on the atmospheric concentration of GHGs (which varies across the different emission scenarios referred to earlier), the shadow price of carbon is currently cited as around £25/t CO_2e. The relationship between costs and benefits can be represented diagrammatically by a Marginal Abatement Cost Curve (MAC), as shown below. The curve slopes up from left to right and gains in steepness, showing that the costs of additional mitigation become progressively higher the greater the level of total mitigation that is sought.

37. The MAC also divides into three segments with a lower segment (lower left) relating to measures that have negative costs and actually increase farm profitability, a middle segment that imposes private cost to farmers but overall positive net benefits to society, and an upper segment (upper right) that actually costs more to implement than the benefits delivered to society.

Stylised Marginal Abatement Cost Curve for CO_2e



38. The economically justifiable level of agricultural mitigation thus depends jointly on the shape of the MAC and on the shadow price of carbon, with the economically justifiable level often being significantly less than the technically feasible level. In the absence of detailed cost data for Scottish or even UK implementation of many mitigation techniques, it is difficult to confidently identify unambiguously cost-effective options. Nevertheless, the example options presented in Table 22 can be viewed alongside the stylised MAC to draw some general conclusions.

39. First, available information does strongly suggest that best management practices offer "win-win" solutions (lower left segment of the MAC). That is, for example, gradual on-farm adoption (and regular maintenance) of modern machinery and buildings when they are due to be replaced delivers improved energy efficiency whilst enhanced nutrient budgeting and manure management can also result in both lower farm expenditure and lower emissions. The private and social cost-effectiveness of altering livestock diets or rearing systems is less clear given possible implications for GHG emissions elsewhere and the current marketing image of extensive Scottish livestock.

40. Second, available information also suggests that currently socially cost-effective mitigation (middle segment of MAC) probably includes the restoration of degraded soil, accelerated woodland creation and the use of biomass for energy. All three impose costs on farmers and will require public assistance to either offset private losses and/or support capital infrastructure investments.

41. Third, other options, such as bioethanol or biogas from anaerobic digesters appear to currently require even higher levels of public support (upper right segment of MAC) and to have less certain net effects on GHG emissions. Hence, at present, even when technically feasible, the cost of reducing emissions by one tonne exceeds £25 for some options – which are therefore not currently worth adopting from society's perspective. However, the shadow price is expected to rise over time and new technologies and greater familiarity with current technologies may lower costs such that more options become viable in the future

42. Such calculations are hindered further by the need to account for net emission effects elsewhere in the supply chain or in other locations. For example, reducing Scottish livestock production would lower domestic emissions – but not necessarily global emissions if similarly polluting overseas production increased as a result, a phenomenon referred to as `leakage`. Equally, encouraging cereal production for intensive livestock rearing or bioethanol production may have a relatively small, or even negative, net effect on emissions whilst also distorting commodity markets for grain.

43. In addition, due to the multi-functional nature of farming, efforts to reduce agricultural GHG emissions may have positive or negative effects on other public good or externality aspects of agricultural production, such as biodiversity, water quality or rural community vitality. Accounting for such co-benefits may affect the relative cost-effectiveness of different mitigation options. All other things being equal, apparently low-cost mitigation may be less attractive if it damages other co-benefits; high-cost mitigation may be more attractive if it also delivers other co-benefits. There are clear overlaps here with the principles and systems perspective of sustainable agriculture, including (but not restricted to) organic farming, and with wider debates about sustainable production and consumption.

Table 22: Selected examples of Scottish agricultural mitigation options

Category	General Example	Specific Examples	Technical feasibility	Potential emission reductions	Approximate MAC segment	Co-benefit effects
Reducing Emissions	Energy efficiency	Adoption and maintenance of modern machinery	High	Low	Lower left	?
		Adoption and maintenance of modern building design	High	Low	Lower left	?
	Nutrient management	Improved utilisation of nutrients for plant growth	High	Low	Lower left	+
		Improved manure storage	High	Low	Lower left	+
	Livestock management	Reduced roughage intake/improved dietary controls	High	Low	Middle	-
		Dietary supplements/ faster maturing breeds	Medium	Low	Middle	-
	Different agriculture	Fewer livestock (*)	High	Medium	Middle?	-
		Switch to non-ruminant livestock (*)	High	Medium	Middle?	-
Displacing emissions	Bioenergy	Bioethanol/biodiesel: from crops, recycled veg oils etc.	Medium	Medium	Upper right	+/-
		Biomass: from SRC, farm residues, municipal waste	Medium	Medium	Middle	+/-
		Biogas: from anaerobic digestion or housed livestock	Medium	Medium	Upper right	?
Enhancing removals	Soil restoration/protection	Land idling (e.g. set-aside) (*)	High	Medium	Lower left?	+
		Prescriptive restorative management	High	Medium	Lower left	+
		Reduced tillage	Medium	Low	Middle	+/-
	Afforestation	Afforestation	High	Medium	Lower left	+/-

Source: Pareto report www.scotland.gov.uk/topics/agriculture/agricultural-policy/17289/change, derived from a number of different sources, each using very different assumptions, scenarios and reporting styles and relating to different countries, currencies, timeframes and policy contexts - few of the which relate to the UK, let-alone Scotland. Hence the above table is an attempt to collate and present results in a common, qualitative format but inevitably requires some interpretative licence and additional assumptions for extrapolation to the Scottish context. Further research in a Scottish-specific context is needed to provide the necessary accuracy for policy decisions. As a rough guide: for "Technical feasibility", "High" signals an existing technology that may be adopted relatively easily; "Medium" signals either an emerging technology and/or an existing one with some barriers to adoption. For "Potential emission reductions", "Medium" equates to 10% to 50%; and "Low" to less than 10% - all relative to total agricultural emissions rather than the specific targeted source, and thus reflecting both the relative size of the specifically targeted source and the efficacy of the measure on that source. For "Approximate MAC segment" see section VII above. "Lower left" indicates a positive impact on profitability, "Middle" indicates some doubt over private profitability and/or capital investment requirements, but still overall social net benefits, "upper right" indicates not only a private loss but also a social loss – with all three taken relative to a shadow price of £25/t CO_2e and all highly dependent on prevailing market conditions and policy incentives. A "(*)" signals dependency on uncertain producer or consumer behaviour. Specifically, the apparent current fragile viability of some livestock operations and the possibility of domestic emission savings simply being offset by increased emissions from imported meat products. For "co-benefits", "+" signals positive effects, "-" negative and "+/-" either possibility depending on context.

Encouraging mitigation

44. Any mitigation option requires some adjustment to agricultural practices. In some cases, for best management practices not currently adopted widely, farm profitability may increase. Indeed, estimated reductions of around 6% in annual sectoral emissions since 1990 and forecast further savings of a similar level by 2025 are largely attributable to individual farmers autonomously pursuing more profitable operations. However, for many mitigation options, on-farm costs will be incurred in the form of income forgone or extra effort expended. In these cases, the private cost will be borne by individual farmers whilst the benefit will accrue to society.

45. Hence, as with other examples of public goods and externalities associated with agriculture, whilst some farmers may have altruistic motives and/or be swayed by social pressures, most will require active encouragement to adopt additional mitigation options.

46. Essentially, the policy choice is between either incentivising or obliging (via regulatory controls) farmers to engage in significant mitigation activity. In this respect, climate change may pose some fresh challenges, but the types of issues arising are relatively familiar from recent trends in the evolution of the expectations placed upon agriculture by society. That is, increasingly, agriculture and land use more generally are viewed not only as providing commodities such as wheat and beef, but also non-market benefits (public goods and externalities) such as ecosystem services and, as with GHG emissions, pollution reduction. Climate change offers yet another compelling argument for better co-ordination across different aspects of land use policy.

Regulatory and Incentive mechanisms

47. Although their relative efficacy is yet to be determined, the new Scotland Rural Development Plan does include a number of climate change incentive packages to encourage mitigation activities. Amendments to application criteria, to prioritise climate change, could encourage the uptake of such measures. However, the level of funding available for Rural Development Contract measures is constrained, and thus the aggregate effect on emissions may be limited unless additional funding is offered. Moreover, the ability of SRDP measures to deliver significant emission savings (and other desired co-benefits of land use) is also restricted by the payment levels being constrained to compensation for income forgone and costs incurred, rather than the value of emission savings. This inevitably lowers the relative attractiveness of SDRP measures given other policy and market influences, such as high grain prices.

48. As an alternative, regulatory approaches are already used to address other diffuse pollution problems associated with land use, notably nitrates and sedimentation in watercourses. Hence measures similar to those applied under the Water Framework Directive (WFD) or Nitrate Vulnerable Zones (NVZs) could be extended to address climate change issues. Equally, cross-compliance aspects of the Single Farm Payment (SFP) under Pillar I of the CAP could be extended to include measures expressly related to reducing GHG emissions. The latter “greening of Pillar I” could avoid some of the funding and administrative issues associated with Pillar II measures.

49. More imaginatively, the value of emissions could perhaps be better reflected through market mechanisms based on carbon trading, if measurement accuracy could be improved and monitoring costs reduced. Whilst the current EU Emission Trading Scheme (ETS) would be administratively too costly to apply to agriculture, there may be scope to use supply-chain or industry codes of practice or quality assurance schemes to underpin some form of trading or voluntary carbon off-set scheme. In this context, the stated intention of the New Zealand Government to include their agricultural sector in an ETS by 2013 is extremely relevant and interesting.

Achievable mitigation

50. With current technologies, the level of technically achievable agricultural mitigation is clearly significant but constrained by biological realities. For example, methane production from enteric fermentation can be reduced but not eliminated completely whilst sequestration into organic soil carbon has an upper bound, a saturation point. Equally, there is a finite limit to the volume of biofuels or biomass that can be grown in Scotland.

51. However, the technical limits to mitigation are generally less binding than the constraints imposed by economic trade-offs, whether expressed quantitatively in terms of shadow carbon prices or more qualitatively in terms of political/social acceptability and priorities. The latter include consideration of co-benefits such as landscapes and biodiversity but also strategic issues such as food and energy security.

52. As a specific example, significant reductions in emissions from Scottish agriculture could be achieved through radically lowering the volume of production and/or by changing the composition of output to reduce the number of ruminant livestock. Technically, this is relatively straightforward. However, it might have serious implications for a number of co-benefits, including maintenance of semi-natural habitats and for the economic structure of not only rural areas but also the wider food manufacturing sector. Moreover, unless matched by changes in consumption patterns (i.e. consumer diets), any apparent GHG emission savings might be illusionary due to “leakage” to production abroad. Whilst debates about sustainable consumption and production are highly relevant to tackling climate change and are related to comments about the need to join-up across government, they are outwith the remit of ACCSG: an intentional policy of dramatically reducing the size of the agricultural sector is not recommended here.

53. However, it is recognised that the decoupling of CAP support and current market conditions will by themselves lead to some reduction in livestock production and therefore GHG emissions. Indeed, most of the reported reduction in emissions since 1990 and some of the anticipated further reductions by 2025 are attributable to lower livestock numbers. Wider adoption of best management practices – possibly requiring enhanced information and advisory services - will also contribute to total anticipated savings by 2025 of around 12%-15%, achieved autonomously through the actions of individual farmers seeking to improve farm profitability.

54. However, achieving mitigation beyond this autonomous level will require active public intervention in the form of additional regulatory and incentive measures. Whilst definitive figures do not exist, the technical potential and apparent cost-effectiveness of soil restoration and appropriate woodland creation seem to offer the most likely route to further savings in the short-run, perhaps of the order of a further 6%-10%. A higher shadow price of carbon and/or technical advances would offer higher net savings through additional mitigation effort. Given the reversibility risk of sequestration, measures may also be required to protect existing stores of organic carbon – such as peat soils and standing timber – from adverse management. This may become increasingly important if commodity market conditions continue to favour an expansion of arable production.

VIII. Recommendations

55. The preceding sections have identified the main issues surrounding agriculture and climate change in Scotland. Addressing these issues requires joint action across various arms of government, to improve the consistency and co-ordination of policy objectives, funding and implementation not just within agriculture but across land use more generally. It also requires joint action across the agricultural industry, the research community and other stakeholder groups. Consequently, after due consideration, ACCSG has agreed four groupings of key recommendations.

Recommendation 1: Research and development needs.

56. To be effective, policies and actions to combat climate change need to be grounded in a sound evidence base. Currently, various Research and Development activities related to climate change and farming systems are underway in Scotland – some of it sponsored directly by the Scottish Government, those commissioned at the Scottish Government Main Research Providers being summarised recently by Matthews et al (2008) (Annex D). It is essential that this Scotland-based capacity is maintained to provide focussed adaptation and mitigation solutions to Scotland`s particular climate change challenges. To reinforce this, particular emphasis needs to be paid to certain aspects.

57. First, **on-going developments in UK-level scenarios and projections for climate change must be monitored**. Existing research to interpret these within and across Scotland must be updated and extended to more sites – particularly in the Highlands and Islands – to identify likely regional variation in, for example, length of growing season and susceptibility to drought or flooding plus pests and diseases. Moreover, the UKCIP08 scenarios represent an important step-change towards developing a more probabilistic risk-based framework that incorporates uncertainty, and new research is required to develop and refine these risk based approaches for agriculture and other land uses, including spatial and temporal variability such as extremes.

58. Second, **the methodological basis for estimating and reporting agricultural emissions must be improved to more accurately reflect the baseline and on-going sectoral position**. Failure to do so risks misdirecting mitigation efforts by misrepresenting the volume and pattern of emissions and industry attempts to adjust. Given the role of the National Inventory within international reporting, revisions to data sources and estimation techniques need to be co-ordinated across the UK (Defra has already initiated some work in this area). Improved estimation procedures will also help in “carbon proofing” policies and in monitoring emissions in relation to targets likely to be set for the sector.

59. **Third, further research must be conducted within the Scottish context to identify and cost both adaptation and mitigation options, to assess their individual practicalities and their relative cost-effectiveness rankings**. This must encompass genetic, agronomic and environmental research into adaptation but also adjustment to business and management structures – including financial and risk management, and household behaviour and choices – in response to challenges and opportunities. Research priorities include durable resistance to likely pest and pathogen challenges, water and nutrient acquisition and internal efficiency in plants, developmental adaptation of plants to stress, and carbon and nitrogen cycling and sequestration in soil plant systems. The principles of sustainable agriculture, for example those implemented in organic farming standards, are highly relevant here. That is, a sustainable systems perspective is needed to account for both biophysical and socio-economic linkages and effects, particularly the impact of human resources on overall ecosystem services, but also driving forces. Farming is subject to numerous pressures and the relative importance of climate change alongside on-going CAP reform, volatile commodity markets and trade liberalisation needs to be considered. In this context, research into the capacity of different farm types and regions to adapt is also merited to identify vulnerable groups or areas in need of particular assistance given prevailing economic circumstances.

Recommendation 2: policy design needs.

60. Tackling the challenges posed by climate change requires appropriate policy responses. Several key aspects of this may be identified.

61. First, **better integration between currently separate policy themes such as agriculture, forestry, deer management, flooding and biodiversity – all of which are linked to land use and require some degree of spatial co-ordination and co-operation across different parcels of land and therefore different farms – must be pursued**. This is essential because agricultural climate change issues can not easily be separated from other aspects of land use policy, or from broader sustainable production and consumption issues. This echoes recommendations from other perspectives where a need for institutional change to join-up across different aspects of land use policy has also been noted.[3] However, it is essential that there is co-ordination and consistency of climate change policy across all other areas of the economy. In particular, adaptation and mitigation options need to be compared across, not just within, sectors to ensure comparability of true costs (including the shadow cost of carbon and other co- and dis- benefits) and application of these options. Failure to do so may impose disproportionate burdens on some sectors, raising total costs to the economy. Hence agricultural policy and interest groups should seek clarity and consistency of approach to climate change targets and responses across all sectors. In addition, since it is not possible to set both prices and quantities, the compatibility of emission reduction targets and policy responses with the quoted shadow price of carbon needs to be clarified

62. Second, **recent experience of incentive schemes under Pillar II of the CAP and of regulatory controls under (especially) NVZs or the WFD must be used as a guide to how best to encourage Scottish land managers to respond to climate change**. Research to identify and cost

[3] www.scotland.gov.uk/publications/2002/06/14888/5503

adaptation and mitigation options will be relevant here, but so too will an improved understanding of the context for adoption and the barriers to behavioural change – such as lack of awareness, high capital costs, and perceived risks arising from policy, market or technological uncertainties.

63. Third, in the short-run, **the scope for modifying SRDP measures and funding and/or enhancing cross-compliance to better control net emissions must be explored**. This links to the previous recommendations regarding identifying and costing mitigation options, but also on improving measurement of emissions. There is a need to avoid `one size fits all` policies, instead having policies structured to allow for localised flexibility, whilst achieving national aims. For the longer-term, **attention needs to be paid to designing market mechanisms to promote mitigation**. In this context, progress in New Zealand towards agriculture's inclusion in an emission-trading scheme should be explored.

Recommendation 3: industry action needs.

64. In responding to the challenge and opportunities posed by climate change, individuals and representative bodies across the industry have a key role to play.

65. First, in adapting to climate change, **farmers and other land managers need to be aware of the potential positive and negative influences of climate change and adjust their business practices accordingly.** This includes both within-season adjustments to, for example, the timing of field and marketing operations but also longer-term adjustments to, for example, choice of cultivar and livestock breed, mix of enterprise and business structure and land use system.

66. Second, **farmers and other land managers need to contribute to mitigation of anthropogenic drivers of climate change and to helping wider society adapt to climate change.** This will require wider adoption of current best management practices – such as nutrient budgeting and energy efficiency informed by carbon and energy audits - but also (given appropriate policy support) more significant adjustment to the nature of land management in line with sustainability principles. A key area will be in matching applications of fertilisers and manure/slurry to plant growth conditions to reduce nutrient wastage and N_2O emissions, with possible co-benefits in reduced water pollution. Further examples include soil and wetland restoration, woodland creation, and renewable energy generation.

67. Third, **representative industry bodies at all stages of the supply-chain need to acknowledge the challenges and opportunities of climate change** – including sectoral responsibilities - and then to help shape and guide collective and proportionate responses in collaboration with government, research institutions and other stakeholders.

68. Fourth **some of the most important measures that land managers can take to mitigate climate change or adapt to its impact on the environment are likely to be more effective if they are taken collaboratively, acting together at the landscape or catchment scale.** Such an approach is likely to be particularly advantageous, for example, in relation to management for reducing the risk of flooding, making better use of animal waste as a substitute for chemical fertilisers (as a means of reducing emissions of nitrous oxide), and connecting isolated and dispersed habitats to give more scope for animals (and possibly plants) to move through the countryside. There is an important role for the SRDP in encouraging this co-operation, and collaboration between land managers applying for Rural Development Contracts could significantly increase the scheme's ability to contribute to Scotland's Climate Change Programme.

Recommendation 4: communication needs.

69. For research findings and policy mechanisms to be effective, it is imperative that key messages regarding the nature and challenges of climate change and the opportunities for adaptation and mitigation are communicated to the agricultural industry. Achieving this is likely to require a mix of different methods but there are clearly roles to be played by government and its agencies, by advisory services, by educational and research groups, and by industry bodies. A dynamic and ongoing approach to this work is necessary, including monitoring of the extent of success in getting the messages across.

70. First, **consistent and key messages must be agreed and methods for communicating them to different target audiences identified**. **This should be informed by professional communication experts**, but is likely to focus on raising awareness of the general challenges and opportunities presented by climate change as well as the specifics of particular adaptation or mitigation options. The DEFRA funded Farming Futures approach (www.farmingfutures.org.uk), the NFUS Business Guide Factsheets and the SAC Climate Change website provide good examples of what can be achieved.

71. Second, **established communication channels - such as codes of practice, newsletters, trade-shows and seminars - should be exploited as communication mechanisms for general information**. This includes ensuring that guidance relating to land use (for example protecting water quality) offers advice consistent with climate change objectives, whether released through government and its agencies or through stakeholder bodies.

72. Third, more **focussed, bespoke, interactive, facilitated, communication approaches require to be adopted. A number of recommendations that have been put forward for adaptation and mitigation of climate change will require not only communication and advice using conventional approaches but also a more interactive approach. Such an approach needs to engage farmers in determining solutions that are relevant to their operations and for which they take responsibility and ownership.** The approach should be developed within the context of Rural Development Contracts and Leader initiatives to enable facilitation and build regional capacity and expertise in developing a local climate change adaptation and mitigation strategy. Such a strategy could focus particularly on local needs, for example at river catchment level, to develop flood mitigation and pollution protection strategies, and in other circumstances collective and collaborative approaches to woodland regeneration and establishment. The approach needs to be linked to other options such as demonstration and monitor farms, web based ‘carbon calculators’ and practitioner champions.

Conclusions

73. Drawing on a range of evidence, this report summarises the ACCSG’s findings regarding the implications of climate change for Scottish agriculture and offers a number of recommendations for further action. Responsibility for taking these forward rests jointly with the Scottish Government and its agencies, but also the industry and other stakeholder bodies. It is their responsibility to collectively rise to the challenge.

Annex A

ACCSG REMIT

AGRICULTURE AND CLIMATE CHANGE : STAKEHOLDER GROUP - TERMS OF REFERENCE

Background

A Forward Strategy for Scottish Agriculture: Next Steps, published in March 2006, recognised that there is mounting evidence about the prospect of significant climate change. Noting that the industry can make a contribution towards mitigating climate change, but that there are also business opportunities, it recommended that a stakeholder group should be established **to evaluate and monitor agriculture's response to climate change, through mitigation and adaptation (including the potential for related business opportunities)**.

This note sets out proposed terms of reference for this stakeholder group.

Mitigation

1. To consider, and make recommendations on, practical measures that can be taken within the agricultural industry to contribute to the Scottish Executive's climate change objectives, and ways of facilitating the adoption of these measures.

The scope of this work is likely to include consideration of practical measures to stimulate reductions in food miles; reduction in fertiliser (organic and inorganic) and livestock emissions (including handling of waste); production of alternative energy sources from biomass; production of industrial materials to replace fossil fuel sources or materials that require high energy use for production (eg concrete); maintenance of stores of carbon in soils; carbon sequestration in growing trees; and increased energy efficiency.

Adaptation

2. To consider, in the light of available projections of the likely impact of climate change in Scotland, ways in which the agricultural industry could adapt, and to make appropriate recommendations to stimulate action.

The scope of this work is likely to include consideration of the need (i) to adapt farming systems in response to threats of extreme weather events, of changing weather patterns (including the risks of reduced water availability in summer and of increased flooding in winter), and of new and more *vigorous pests and diseases; (ii) to optimise opportunities that may arise, including those for new crops and new markets; and (iii) to make land management changes in order to increase public and environmental benefits (eg alleviation of downstream flood risks and provision of habitat corridors for species migration).*

Methods of work

This is a complex and challenging task. The group will be expected to complete its work by March 2008, but it is recognised that in this timescale it may not be possible to cover all aspects of the terms of reference in a fully comprehensive manner. In order to make progress, the group should focus on the following activities:

- agree, by December 2006, an action plan setting out a programme of work (and milestones) for the following 15 months;

- identify relevant research outputs in order to make full use of existing knowledge and identify knowledge gaps;

- if further research is deemed necessary, make specific proposals for such research and possible sources of funding (bearing in mind that it will need to compete with other research priorities and that, depending upon its nature, research may not be completed before the work of the group comes to an end);

- make proposals for specific actions that the sector can take to respond to the challenge of climate change; identify barriers that may be inhibiting action and ways in which these can be tackled; and suggest lead organisation(s) to take forward action;

- use whatever means the group considers most appropriate (eg publications, consultation exercise, seminars, conference) to communicate its findings to wider audiences within Scotland's land-based industries;

- prepare a final report by March 2008.

Annex B

AGRICULTURE AND CLIMATE CHANGE STAKEHOLDER GROUP : MEMBERSHIP

Henry Graham, Chair

Jamie Skinner/Douglas Bell, Scottish Agricultural College

Hugh Clayden, Forestry Commission Scotland

Carey Coombs, Environment Link

Jonathan Hall, NFU Scotland

Peter Gregory/Adrian Newton, Scottish Crop Research Institute

June Graham, Scottish Environment Protection Agency

Robin Matthews, Macaulay Institute

Jeff Maxwell OBE FRSE, Agriculture Strategy Implementation Group

Peter Pitkin, Scottish Natural Heritage

Karen Smyth, Scottish Rural Property & Business Association

Ben Dipper, Scottish Government

Jenny Hamilton, Scottish Government

Helen Jones, Scottish Government

Linda Pooley, Scottish Government

Caspian Richards, Scottish Government

Annex C

LIST OF MEETINGS/PRESENTATIONS TO AGRICULTURE AND CLIMATE CHANGE STAKEHOLDER GROUP

Presentations to Agriculture and Climate Change Stakeholder Group

- Guy Winter, (at time of meeting – Scottish Executive Environment and Rural Affairs Department Climate Change Policy Team) on Greenhouse Gas Emissions/Carbon Balance
- Ian Davidson, (at the time of meeting - Scottish Executive Environment and Rural Affairs Department) on Energy Efficiency
- June Graham, Scottish Environment Protection Agency **-** on Water Quality and Availability
- Professor Peter Gregory, Scottish Crop Research Institute - on Pest and Diseases
- Roy and Martin Foster - on Hydro Power
- Jamie Skinner, Scottish Agricultural College - on Adaptation
- Dr John Gilliland OBE, - on the work of Defra Rural Climate Change Forum and Energy Farming
- Dr Andrew Moxey, Pareto, Reviewing and Developing Agricultural Responses to Climate Change
- Susie Gledhill, Scottish Government Climate Change Bill Team
- Iain Morrison, Scottish Government Environmental Quality (Water Pollution Control) an overview of the Bathing Water Report and background to the Farm Scale Biogas and Composting Pilot Project in Sandyhills and Saltcoats
- Wesley Millar/Jamie Gascoigne **–** on Anaerobic Digestion
- Antje Branding, Scottish Government Soils Policy Co-ordination **–** on Anaerobic Digestion Projects in Germany

- Carey Coombs, Environment Link – on the Role of the Organic Farmer and the Soil Association
- John Stocks, Carbon Trust – Implications of Carbon Footprint for Scottish Agriculture
- Hamish Walls, Scottish Agricultural Organisation Society – Co-operation and Energy Efficiency
- Judith Tracey, Scottish Government Flooding Policy – on Flooding Bill for Scotland
- Dr Amanda Thomson, Centre for Ecology and Hydrology – on Land Use, Land Use Change and Forestry
- Chris Nixon, Forestry Commission Scotland – on Scottish Forestry and Mitigating Climate Change
- Peter Pitkin, Scottish Natural Heritage – on Biodiversity and Landscapes
- Patricia Bruneau, Scottish Government Water, Air, Soils and Flooding – on Scottish Soils Policy

Annex D

Integrating climate change research across the Main Research Providers[a] in Scotland

Robin Matthews[4], Adrian Newton[5], Chris Ellis[6], Dominic Moran[7], Chris Glasbey[8], Philip Skuce[9]

Executive summary

1. The need for Scotland to adapt to climate change and move to a low carbon economy is recognized. The rural sector has an important role to play in achieving this transition.
2. Scotland is considering legislation to reduce GHG emissions by 80% from 1990 levels, and also has legally-binding obligations to maintain its biodiversity.
3. The Main Research Providers (MRPs) in Scotland are carrying out a range of work under the strategic research programme which supports climate change adaptation and mitigation, the relevant aspects of which are summed up in the following points.
4. Current work on biodiversity focuses on likely shifts in species distributions, monitoring populations of vulnerable species, and assessing the genetic variation necessary for adaptation to changed climates in crops and semi-natural species.
5. Current soils work is focusing on the potential vulnerability of Scotland's peat soils to release large quantities of CO_2 as temperatures increase, and on greenhouse gas emissions from intensive agricultural systems.
6. Ongoing agricultural research is assessing the likely impacts of climate change on crops and their diseases, livestock and their diseases, and on farming systems. Work is also beginning on adaptations that will be needed in the future in agricultural systems, such as new and tolerant crops, improved livestock, and better management practices.
7. Current research on integrated land use systems is focusing on changes in land capability under climate change, the costs and benefits of renewable energy sources, on changes in consumer demand in the move to a low carbon economy, on the implications of these changes for ecosystem functioning, and on stakeholder perceptions of these changes.
8. In addition to this ongoing research, we suggest that future research must also consider the implications of possible mitigation and adaptation pathways for the trade-offs and synergies between different ecosystem services.

---

[a] The following, with the Rowett Research Institute, are the Main Research Providers to the Rural and Environment Research and Analysis Directorate of the Scottish Government

[4] Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen, AB15 8QH, Scotland.
[5] Scottish Crop Research Institute, Invergowrie, Dundee, DD2 5DA, Scotland.
[6] Royal Botanical Gardens of Edinburgh, 20A Inverleith Row, Edinburgh, EH3 5LR, Scotland.
[7] Scottish Agricultural College, King's Buildings, West Mains Road, Edinburgh EH9 3JG, Scotland.
[8] BioSS, The University of Edinburgh, JCMB, King's Buildings, Edinburgh, EH9 3JZ, Scotland.
[9] Moredun Research Institute, Pentlands Science Park, Bush Loan, Penicuik, Midlothian EH26 0PZ, Scotland.

Policy context

1. Climate change is widely recognised as the most serious environmental threat facing our planet today, and is likely, therefore, to become central to policy-making and land-use decision-making within the next decade or two, and remain so for many years thereafter. In the Scottish Executive's Climate Change Strategy (Scottish Executive, 2006a), the need to move to a low-carbon economy by 2050 is emphasised, and, recognising that some climate change will occur even if emissions are successfully reduced, some of the adaptive responses that might be made are outlined. Subsequent policy documents for the forestry and agriculture sectors have also been published (Scottish Executive, 2006b; Scottish Executive, 2006c), both of which acknowledge the contribution of these sectors as sources and sinks of GHGs. Similarly, the Scottish Biodiversity Strategy (Scottish Executive, 2004) explicitly recognises the threat of potential shifts in species' range, and a need, therefore, to minimise limits to dispersal and migration. In addition, the Scottish Government proposed in June 2007 a target for reduction of GHG emissions of 80% by 2050, and studies are currently underway to evaluate possible means by which this target may be achieved. Consequences of GHG reduction targets for Scotland's environment, land use, and rural communities need to be better understood, as do the management systems needed to encourage sustainable landscapes in the face of changing climate.

2. Scotland also has obligations to contribute to the UK's monitoring and reporting of greenhouse gas (GHG) emissions and to the emission reductions required by Annex 1 countries of the Kyoto Protocol. Future policy directions are also likely to be influenced by the increasing prominence of carbon markets and the use of a shadow price for carbon equivalent emissions for judging policy decisions on mitigation. Both aspects have been given greater prominence in government policy-making since the Stern (2007) review and the promotion of the shadow cost of carbon in regulatory decision-making (Price *et al.*, 2007).

Current climate change research in the Main Research Providers

3. Climate change research in the Main Research Providers (MRPs) spans a range of disciplines, providing the ability to integrate natural and social sciences to understand the drivers and biophysical responses of climate change, the economic efficiency of mitigation and adaptation actions, and the social contexts that are important to government decision-making. In the remainder of this document, we consider how impacts, mitigation and adaptation issues intersect with the broad research areas covered by the MRPs.

Biodiversity

4. In addition to the climate change policies mentioned above, MRP research on biodiversity is also driven by targets specified in national and international biodiversity policy, particularly the Convention on Biological Diversity (CBD), the Global Strategy for Plant Conservation (GSPC), the UK Biodiversity Action Plans (UKBAPs), the Scottish Biodiversity Strategy and the SEERAD Strategy for Agricultural, Biological and Related Research.

5. Both RBGE and MLURI are studying the likely impacts of climate change on species distribution at multiple spatial scales. Several predictions have been made using statistical models of the direction, degree and likelihood of species shifts under different IPCC scenarios, indicating which species or vegetation types should be closely monitored or protected (e.g. by translocation or the mitigation of other stresses).

6. Monitoring of the impacts of climate change on the growth and development of species is also carried out – the RBGE, for example, has its own phenology study of more than 150 species, providing a facility to characterise species into functional groups according to their climatic response. The RBGE also participates in the Scottish Forestry Phenology Project (SFPP), with discussions underway to join the International Phenology Gardens Project co-ordinated by Humboldt University (Berlin), with sites throughout continental Europe. A particular focus at RBGE is on monitoring and understanding the impact of climate change on the growth and distribution of Scottish cryptogams (e.g. mosses, liverworts, lichens, fungi and ferns), for which Scotland has an international responsibility. Similarly, the RBGE's work on the flora of Socatra, Nepal, and several tropical countries is monitoring the impact of climate change on biodiversity globally. In collaboration with CEH, RBGE is incorporating data from taxonomy and functional ecology into single datasets, providing synthetic tools for species identification and the analysis of ecosystem structure and function. These international studies will be complemented by a new initiative undertaken with partners in China.

7. In related work, RBGE uses molecular marker techniques to examine the potential of species to adapt to environmental change – for example, examining hybridisation and the competitive performance of native and non-native bluebell species along climatic gradients. Similar work is being carried out at SCRI on barley and potato, and on pests and pathogens such as *Phytophthora*, *Aphis*, *Rhynchosporium* and *Erwinia* and persistence of animal and human pathogens in soils. Crop ecology work at SCRI seeks to understand how the biodiversity of arable systems interacts to contribute to their resilience to external shocks and pressures.

8. The RBGE also provides resources used for climate change studies – their photographic archives are used for time series studies of landscape change, and their expertise in diatoms provides taxonomic support for palaeoclimatologists.

9. Rather than simply making predictions of species re-distribution, work is increasingly focusing on identifying uncertainties associated with responses to climate change, and on the more complex interactions between species, including humans in both rural and semi-natural environments, as they adapt. Current predictions are based on rather simplistic relationships between species distributions and climate, and there is a need to obtain baseline data that take account of indirect effects exerted through relationships between species and through changing human impacts on the environment as a result of adaptation. This information can then be used to identify where species compositions might be altered with southerly species arriving and/or northerly species retreating. Research is also needed to understand the effectiveness of the existing conservation network during a period of climate change, to identify changes in conservation policy that may be required to meet biodiversity targets, and to understand to what extent climate change threats might be mitigated by management within species' existing ranges.

Soils

10. At MLURI, work is ongoing to assess the stock of C in soils and peats across Scotland so as to characterize this potentially vulnerable C pool. In collaboration with the University of Aberdeen, the ECOSSE model of C turnover has been specifically developed to describe processes in the organic soils prevalent in Scotland. It is planned to use ECOSSE within a GIS framework to assess the impact of both land use and climate change on C cycling at the 1 km^2 scale across the country. The resampling over the next three years of the National Soils Inventory points, a grid-based set of sampling points across Scotland which were initially sampled over twenty years ago, will provide information on soil C and other properties where any changes may indicate climate change responses.

11. Other modelling studies at MLURI include an investigation of climate change impacts on dissolved organic matter in soils and rivers, and, in collaboration with SAC, on N_2O emissions from agricultural soils. MLURI and SCRI are analysing the potential impacts of altered precipitation patterns on both drought and water-logging, and, under more severe conditions, the implications for increased risk of soil erosion.

12. More detailed process-based field research at MLURI aims at characterizing the carbon fluxes within arable, grassland, woodland, moorland and peatland ecosystems, while work ongoing at SCRI is studying the key processes driving C and N cycling in arable systems, including the role of plants in effecting C transfer to soils. Understanding gained from this work will help to refine the various models of C and N used in climate change studies. These models will then be used to examine how C losses to the atmosphere and N losses to water courses can be minimized, and how improving nutrient use efficiency of crop plants can help to reduce gaseous and leaching losses. This complements work at SAC on quantifying GHG emissions from intensive arable systems, and the development of improved inventories of emissions from the major farming systems that are active in Scotland. SAC is also undertaking work on soil valuation that includes carbon values, which will contribute towards the construction of an accounting framework for positive and negative externalities from agriculture.

Waters

13. The predicted shifts in temperature and precipitation will also have direct impacts on hydrological and biogeochemical cycles, which may lead to changes in river flow regimes or groundwater recharge, and increased frequency of extreme events such as flooding and droughts. Changes in the hydrological regime could also lead to indirect changes in water chemistry, as a result of erosion risk, leaching potential, and biological and chemical processes which are regulated by water availability. Temperature changes may affect physical processes such as freezing, thawing and evapotranspiration, as well as biological and chemical processes, all of which will influence freshwater ecology. These consequences require to be assessed together with identification of appropriate adaptation and mitigation measures, through planning and policy frameworks, for example, implementation of water resources legislation such as the EU Water Framework Directive.

14. Long-term data collected from the Environmental Change Network (ECN) provides invaluable information for detecting changes in water quality such as that brought about by climate change, and will assist in the provision of an enhanced evidence base for its impacts. The potential impact of climate change on riparian ecosystems is currently being examined through an assessment of the relationships between vegetation, climate and the thermal regimes of streams. Many surface waters are currently recovering from nutrient enrichment from atmospheric deposition (S, N). The potential implication of climate change on the recovery of these systems is being examined using a space-for-time substitution method.

15. The process based catchment models of hydrology and diffuse pollution which incorporate a number of climatic variables will be further developed at MLURI to enable improved understanding of transport processes at catchment scales. Future application of these models, using climate change scenarios, will enable the consequences of climate change on runoff processes and the generation of diffuse pollution to be evaluated and further to be linked with ecological responses. This will enable the identification of aspirational and achievable targets for recovery of freshwaters, given the hysteresis of their responses to pollutant pressure, nutrient enrichment and removal. In addition, factors such as frequency of flooding and drought conditions will be assessed. Specific research will be undertaken on dissolved organic matter to interpret the results of process studies on

controlling processes and transport mechanisms in relation to climate change and hence to evaluate the potential impact on catchment receiving waters.

Agriculture

16. Several studies at the MRPs are evaluating the likely impacts of climate change on agricultural systems in Scotland, and how such change might be mitigated and/or the systems adapted to cope with the change. SAC is currently undertaking a UK-wide assessment of climate impact on livestock and crop systems and the costs and benefits of public and private adaptation strategies. This overarching project combines existing studies on the introduction of new breeds, modified feed regimes, changes in breeding and lactation cycles, changes in animal appetite and health, and increased veterinary costs due to longer disease seasons. Further work is looking at impacts on beef, sheep and dairy production systems, both in terms of impacts and also on the carbon foot print of such systems. Related to the latter is research on the genetic and nutritional effects on methane production by cows, with the aim of developing new breeds with reduced emission potential.

17. SCRI is currently analysing the relationship between long-term climate variables and crop yields in the Dundee region, to develop ways of dealing with potential shifts in geographic distributions of pests and diseases as a result of climate change. Collaborative work between SCRI and SAC aims to quantify the flows of energy and matter in arable-grass systems, and use this to understand the resilience of such systems in the face of climate change. At MLURI, the LADSS farm-scale decision support system is being used to assess impacts of UKCIP02 climate change scenarios on the sustainability of farming systems across Scotland, and how uncertainty in the climate data influences the decision-making processes of farmers. This relates to work at SAC quantifying the C foot print of alternative farming systems, including renewable energy options (i.e. biofuels, wind energy).

18. Another area of work anticipates some of the adaptations that will have to be made in agriculture as the climate changes. For example, the chilling requirement needed for synchronous blackcurrant cropping may not be possible with warmer winters. SCRI is examining how crop varieties recently developed for new management practices (e.g. growing fruit in warmer polytunnels) might also be used in different future climates. SCRI is also considering the development of new crops (including energy crops and those producing molecules of high value) to take advantage of more favourable growing conditions. Research on root architecture in barley should help develop new varieties able to withstand the drier conditions of the future. Similarly, ongoing work on the epidemiology, geographic distribution, and population structure of pests and diseases is providing the underpinning knowledge of how these will respond to climate change, and genetic and molecular research is being used to develop durable resistance solutions. These resources will be also be deployed if new and emerging diseases, such as root-knot nematodes (*Meloidogyne* spp.), *Erwinia chrysanthemi* and *Phytophthora ramorum*, or pathogens such as cereal rusts and *Fusarium* species characteristic of warmer summers, appear in Scotland.

19. In relation to animal diseases, both MRI and SAC have ongoing surveillance activities and research into vector borne disease of livestock and wildlife, which will help to identify new diseases that may be introduced as the climate warms – Bluetongue in sheep and the West Nile virus are current examples of exotic viral diseases that may affect Scotland in the future. Under warmer temperatures, vector-borne diseases associated with midges and ticks and clinical disease associated with the highly pathogenic nematode *Haemonchus contortus* are likely to become more prevalent,

while the reductions in hard frosts and winter temperatures will allow the *Toxoplasma gondii* parasite of pigs and sheep to survive better. Under warmer, wetter conditions, the incidence of roundworm and liver fluke is also likely to increase as a result of extended parasite seasons and the survival of infectious stages over winter on pasture. An increased incidence of parasitism would increase the reliance on anthelmintics and exacerbate the impact of resistance.

Integrated land use systems (including forestry)

20. This includes work on the interactions between climate change and the way land is used. MLURI, for example, is evaluating the impact that scenarios of climate change will have on the suitability of land for agriculture, forestry and other uses. This takes previous land suitability studies and superimposes changes in temperature and rainfall on them to predict changes in land suitability classifications. Work so far has shown the sensitivity of these classifications to changes in rainfall, which has significance for land classed as prime agricultural land for planning purposes.

21. More detailed work at SCRI and SAC focuses on the construction of a hierarchical framework and predictive approach for optimising properties of the arable-grass production systems of east Scotland, including ecological resilience, aesthetic features of the landscape and its wildlife, farm livelihoods, food security, and choice for producers and buyers. Field-level simulation models incorporating the influence of climatic variables on crop growth are being constructed within the framework, and will be used to assess how farmer decision-making and the resulting changes at the field level upscale to regional and national levels. The databases and models being developed will be linked with models of climate and land use in Scotland.

22. Similarly, MLURI are developing and using the coupled human-environment People and Landscapes Model (PALM) which links household decision-making to soil carbon, nitrogen and water dynamics, in an attempt to understand the complex feedbacks between human and biophysical processes. The model is currently being used to investigate taxation and incentive policies aimed at reducing GHG emissions from land use, and to predict productivity and carbon sequestration potential of short-rotation coppice (SRC) plantations across Scotland, which links into work at SAC on evaluating the economic potential and uptake of SRC and *Miscanthus* in the UK. Other work at MLURI is using agent-based models to investigate the behavioural changes of people in rural communities that will be required to move to a low-carbon economy, in terms of their choices of domestic energy sources (e.g. renewable or fossil), food preferences (e.g. local or imported), and transport choices (e.g. fuel sources, homeworking, etc.). This work will produce scenarios of demand for various commodities which will provide input into a dynamic land use change model to evaluate the likely impact on land use that these demands may have.

23. The modelling work at MLURI is informed by interactions with stakeholders using Q-methodology, which aims to define existing viewpoints and perceptions in Scotland concerning the contribution of land-use and forestry sectors to climate change policy, and the criteria of climate change policy solutions that are important to people. It is hoped that the stakeholder engagement and modelling together should assist in developing a common view on climate change mitigation and adaptation land use policy options, thereby avoiding conflicts and identifying incentives to encourage public activity in support of climate change mitigation.

24. Increasingly the focus will be on the whole rural sector, including rural industry and the wider rural population, rather than just the agricultural component, and to examine its capacity to adapt to climate change, including its contribution to GHG mitigation. One theme being developed at MLURI is the identification of practical and strategic options for rural communities to move towards low carbon economies by reducing GHG emissions, increasing carbon storage, and switching to alternative energy systems. However, often there are tradeoffs between individual interests of making a livelihood and the broader societal goals of mitigating and adapting to climate change, so it is particularly important in developing policy that the cost, benefits and trade-offs required are recognised, to ensure that particular individuals and communities are not disproportionately burdened.

25. Interaction with stakeholders and knowledge exchange is a key part of our climate change activities. Interaction with policy-makers will continue through participation in appropriate strategy groups (e.g. RERAD Agriculture and Climate Change Strategy Group, etc.), and with other stakeholders through various activities (e.g. using agro-meteorological metrics with focus groups to stimulate debate on the nature of adaptations required by climate change).

An integrative framework: human choices and ecosystem services

26. The strategy documents are clear on the need for rigorous, integrated analysis that includes social and institutional factors rather than a piecemeal approach dominated by either the economic or biophysical sciences. This is a significant challenge for researchers, and requires both the breaking down of barriers to interdisciplinary research, and the active inclusion of stakeholders and policymakers.

27. The development of an integrating framework is a useful first step. Such a framework relating to natural resources management is logically at the landscape level, and needs to be a ‘coupled human-environment systems’ framework taking into account the both the socio-economic and biophysical processes occurring at that level. In terms of mitigation and adaptation to climate change, two aspects need to be considered – (a) the *choices* that people in rural communities (in households or firms) make in relation to their energy consumption, their food, their transport, their adaptive responses, and in the case of land managers, the way that their land is used, and (b) the impact that these choices and their related actions have on the tradeoffs and synergies between different *ecosystem services*, and how this affects the sustainability of rural systems. Ecosystem services are nested within the origin and maintenance of biodiversity (cf. Millennium Ecosystem Assessment), i.e. they are functional processes generated by assemblages of species, and their interactions with the physical world. However, a deterministic relationship between biodiversity and ecosystem services remains uncertain, and any potential trade-offs between adaptation and biodiversity conservation represent a particular challenge to integrated decision-support frameworks based on socio-economic models, with biodiversity values widely acknowledged, though difficult to quantify.

28. A possible framework for integrating the range of climate change research in the MRPs is shown in Figure 1. Climate change is seen as the driver of the system, and therefore outside it, although, of course, in the long-term, GHG emissions from within the system will provide feedback and therefore influence the degree of climate change. Climate change influences the functioning of the system in two ways – firstly by direct influence on ecosystem processes and services (impacts), and secondly on the way that actors within the system respond to it, causing change in behaviour, which in turn affects various ecosystem processes (mitigation/adaptation). In terms of changing behaviour to reduce GHG emissions, the key decision-making entities are households and businesses, the latter including farms and other land management units. All rural households make choices regarding their energy consumption, food, and transport, while households managing land additionally make choices regarding land use. All of these have implications for GHG emissions – the first three through the burning of fossil fuels, and the fourth through emissions of CH_4 from livestock, N_2O from fertiliser applications, organic matter management, and offsetting of GHG emissions through carbon sequestration and provision of renewable sources of energy.

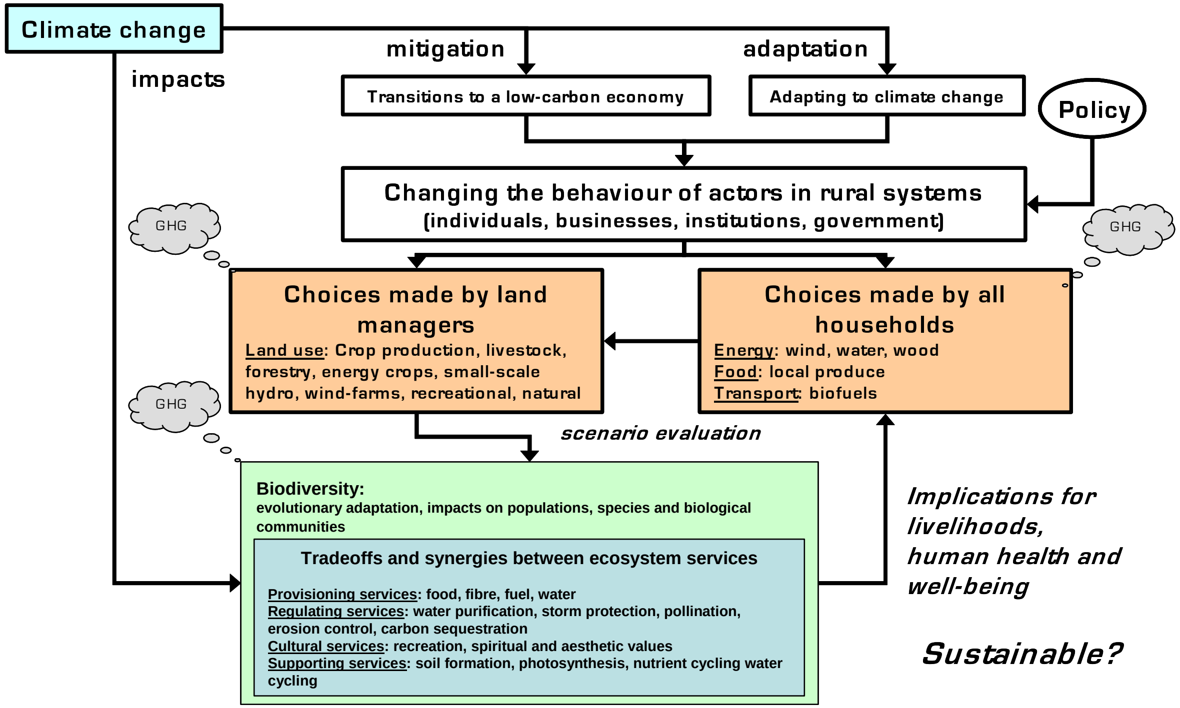


Figure 1: Suggested coupled human-environment systems framework for integrated climate change research by the Scottish MRPs.

29. With the exception of changes in commuting patterns, all of these have implications for the balance of ecosystem services – choices to substitute fossil fuels with biofuels raises issues of where biofuel crops will be grown, choices to buy local food to reduce food miles raises the issue of where the local produce will be grown, while choices to switch to renewable energy sources raises issues of where wind-farms, small-scale hydro schemes, and biomass crops will be located. All of these will influence choices by land managers responsible for different land cover and land management practices, which may have implications for ecosystem services such as C sequestration, water quantity and quality, and biodiversity. Because the total land area is fixed, tradeoffs and synergies will inevitably occur, between mitigation and adaptation mechanisms on the one hand, and biodiversity and ecosystem services on the other. Thus, it is essential to consider the impact of responses to climate change on biodiversity and ecosystem services if we are to understand their impact on the sustainability of the overall system.

30. We recognise that all of the MRPs already work on ecosystem services in some way (i.e. ecology-related, soil-related, water-related, societal valuation, etc.) – the unique focus in the suggested framework is in the linking of all of these and investigating the tradeoffs and synergies that occur between them at the landscape/regional level as humans respond to climate change. The use of appropriate, state-of-the-art statistical and mathematical methods will be critical in all aspects of this work, and will be delivered by BioSS in consultancy and underpinning methodological research.

31. Such an approach is timely. The studies currently being commissioned by the Scottish Government will identify potential trajectories towards a low carbon economy, but the emphasis is then likely to shift to evaluating these adaptive trajectories in terms of whether people will choose to follow them, and what impact they will have on the environment. Moreover, since the Millennium Ecosystem Assessment Report published in 2006 highlighted the serious decline of 15 out of 24 of the world's major ecosystems, interest in ecosystem services has risen up the research agenda of a number of organisations, and the tradeoffs and synergies between them is becoming a key topic. The current debate on potential conflicts between bioenergy production, food production, and forests is one example. As it is also an underlying concept of SG-RERAD's Global Change and Local Responses theme in their future Research Programme, the Scottish Main Research Providers are in a unique position to use their expertise to link a topic of global importance (i.e. climate change) to another that is likely to become increasingly important in the future (i.e. ecosystem services).

References

Price, R., Thornton, S. & Nelson, S., 2007. 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. Economics Group, Department for Environment, Food and Rural Affairs, London. 22 pp.

Scottish Executive, 2004. *Scotland's Biodiversity: It's in Your Hands*. Scottish Executive, Edinburgh, Scotland. 65 pp.

Scottish Executive, 2006a. *Changing our Ways: Scotland's Climate Change Programme*. Scottish Executive, Edinburgh [online at: http://www.scotland.gov.uk/Resource/Doc/100896/0024396.pdf]. 113 pp.

Scottish Executive, 2006b. *A Forward Strategy for Scottish Agriculture: The Next Steps*. Scottish Executive, Edinburgh, Scotland. 32 pp.

Scottish Executive, 2006c. *The Scottish Forestry Strategy*. Scottish Executive, Edinburgh, Scotland. 86 pp.

Stern, N., 2007. *The Economics of Climate Change: The Stern Review*. Cambridge University Press, Cambridge. 692 pp.

Annex E

KEY REFERENCES

Moxey A.P. : Reviewing and Developing Agricultural Responses to Climate Change. Pareto Consulting 2008

Stern N. : The Economics of Climate Change : The Stern Review. Cambridge University Press, Cambridge 2007

Jackson J., Li Y., Passant N., Thistlethwaite G., Thomson A., Cardenas L., : Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland ; 1990-2005 AEA Technology 2007

Agriculture and Environment Working Group : Custodians of Change. Scottish Executive 2002

Changing Our Ways - Scotland`s Climate Change Programme; Scottish Executive 2006

Choosing the Right Ingredients - The Future for Food in Scotland Discussion Paper 2008

Scottish Executive : A Forward Strategy for Scottish Agriculture : The Next Steps, Scottish Executive 2006

Annex F

ESTIMATED EMISSIONS BY SELECTED SOURCES AND SINKS ASSOCIATED WITH SCOTTISH AGRICULTURE

Table : Estimated emissions by selected sources *and sinks* elements (KT CO_2 equivalent) associated with Scottish agriculture under various IPCC reporting categories, plus percentage change over period and percentage share of each element in total emissions associated with agriculture, ranked by percentage share of 2005 total.

	1990				2005				% change, 1990 to 2005	% share of 2005 overall total
Emission Source (*Sink)*	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total		
Land converted to Cropland (L)	6048.6			6048.6	6561.1			6561.1	8.5%	44.8%
Agricultural soils (A)			4931.0	4931.0			3769.4	3769.4	-23.6%	25.7%
Other cattle enteric (A)		1641.8		1641.8		1593.0		1593.0	-3.0%	10.9%
Sheep enteric (A)		990.7		990.7		796.5		796.5	-19.6%	5.4%
Agricultural fuel use (E)	550.7	1.7	61.2	613.6	588.9	1.7	65.3	655.9	6.9%	4.5%
Dairy cattle enteric (A)		452.2		452.2		427.8		427.8	-5.4%	2.9%
Manure solid storage and dry lot (A)			190.5	190.5			186.5	186.5	-2.1%	1.3%
Other cattle wastes (A)		154.1		154.1		148.4		148.4	-3.7%	1.0%
Grassland remaining Grassland (L)	59.9			59.9	113.6			113.6	89.7%	0.8%
Dairy cattle wastes (A)		111.1		111.1		105.0		105.0	-5.4%	0.7%
Cropland - Liming (A)	134.5			134.5	71.9			71.9	-46.6%	0.5%
Grassland - Liming (A)	133.8			133.8	69.5			69.5	-48.1%	0.5%
Grassland - Biomass Burning (A)	7.6	0.7	0.1	8.3	29.4	2.7	0.3	32.4	288.9%	0.2%
Pigs wastes (A)		28.5		28.5		29.6		29.6	4.0%	0.2%
Sheep goats and deer wastes (A)		23.6		23.6		18.9		18.9	-19.8%	0.1%
Broilers wastes (A)		14.4		14.4		16.9		16.9	17.7%	0.1%
Pigs enteric (A)		14.2		14.2		14.7		14.7	3.4%	0.1%
Manure other (A)			18.9	18.9			14.3	14.3	-24.5%	0.1%
Horses enteric (A)		5.4		5.4		10.9		10.9	103.7%	0.1%
Manure liquid systems (A)			5.9	5.9			5.4	5.4	-8.1%	0.0%
Laying hens wastes (A)		5.9		5.9		4.2		4.2	-29.9%	0.0%
Other poultry wastes (A)		4.0		4.0		2.9		2.9	-26.3%	0.0%
Deer & goats enteric (A)		3.9		3.9		2.1		2.1	-46.2%	0.0%
Horses wastes (A)		0.4		0.4		0.8		0.8	102.7%	0.0%
Field burning (A)		18.3	5.4	23.7		0.0	0.0	0.0	-100.0%	0.0%
Source Total	6938.4	3470.7	5213.1	15622.2	7437.4	3176.3	4041.2	14654.8	-6.2%	100.0%
Land converted to Grassland (L)	*-2320.7*			*-2320.7*	*-2808.8*			*-2808.8*	*21.0%*	*21.5%*

Cropland remaining Cropland (L)	*-78.9*			*-78.9*	*-78.9*			*-78.9*	*0.0%*	*0.6%*
Land converted to Forest Land (L)	*-7547.4*			*-7547.4*	*-10132.7*			*-10132.7*	*34.3%*	*77.4%*
Harvested wood products (L)	*-714.2*			*-714.2*	*-69.0*			*-69.0*	*-90.3%*	*0.5%*
Sink Total	*-10661.3*	*0.0*	*0.0*	*-10661.3*	*-13089.4*	*0.0*	*0.0*	*-13089.4*	*22.8%*	*100.0%*

Note: From Pareto 2008. Figures derived from detailed “pivot table” appendix to the Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland: 1990 to 2005 (Jackson et al., 2007). Direct comparison with Inventory figures and therefore “Changing Our Ways” (Scottish Executive, 2006) may be hampered by differences in source data (see Jackson et al., 2007: pages v & viii) and by the selective (re)assignment of elements from three IPCC categories: Agriculture (A), Land Use, Land Use Change & Forestry (L) and Energy (E). Similarly, for ease of interpretation of individual elements, sinks and sources are identified and summed separately – but the effect of including sinks (especially forestry) to give a smaller net contribution to the Scottish net total of 54,500Kt should be noted. Approximately 15% of the carbon sequestration flux credited to land converted to forest land is derived from former farmland (pers. comm. CEH). Since different representations of these data may give different impressions, clarity of baselines and definitions is fundamentally important

ISBN 978 0 7559 1694 8 (web only publication)