

Integrating climate change research across the Main Research Providers in Scotland

Robin Matthews¹, Adrian Newton², Chris Ellis³, Dominic Moran⁴, Chris Glasbey⁵, Philip Skuce⁶

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 CO₂ 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 tradeoffs and synergies between different ecosystem services.

Policy context

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

¹ Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen, AB15 8QH, Scotland.

² Scottish Crop Research Institute, Invergowrie, Dundee, DD2 5DA, Scotland.

³ Royal Botanical Gardens of Edinburgh, 20A Inverleith Row, Edinburgh, EH3 5LR, Scotland.

⁴ Scottish Agricultural College, King's Buildings, West Mains Road, Edinburgh EH9 3JG, Scotland.

⁵ BioSS, The University of Edinburgh, JCMB, King's Buildings, Edinburgh, EH9 3JZ, Scotland.

⁶ Moredun Research Institute, Pentlands Science Park, Bush Loan, Penicuik, Midlothian EH26 0PZ, Scotland.

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.

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

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

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.

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).

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.

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.

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.

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

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 km² 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.

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 N₂O 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.

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

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.

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.

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

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.

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).

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.

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)

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.

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.

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.

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.

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.

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

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.

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.

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 CH₄ from livestock, N₂O from fertiliser applications, organic matter management, and offsetting of GHG emissions through carbon sequestration and provision of renewable sources of energy.

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

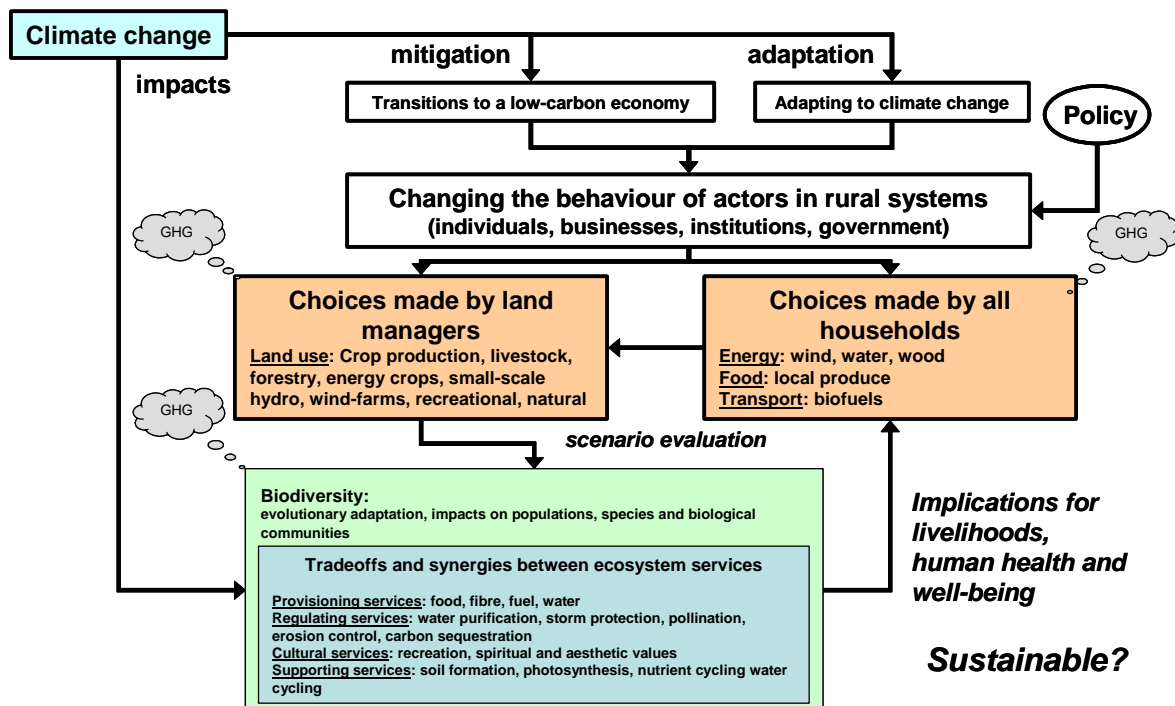


Figure 1: Suggested coupled human-environment systems framework for integrated climate change research by the Scottish MRPs.

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.

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.

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.

29 March 2008