An Integrated Assessment approach to conduct analyses of climate change impacts on whole-farm systems.

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Abstract: This paper argues that an integrated assessment approach, combining simulation modelling with deliberative processes involving decision makers and other stakeholders, has the potential to generate credible and relevant assessments of climate change impacts on farming-systems. The justification for the approach proposed is that while simulation modelling provides an effective way of exploring the range of possible impacts of climate change and a means of testing the consequences of possible management or policy interventions, the interpretation of the outputs is highly dependent on the point of view of the stakeholder. Inevitably, whatever the responses to climate change, there will be trade-offs between the benefits and costs to a range of stakeholders. The use of a deliberative process that includes stakeholders, both in defining the topics addressed and in debating the interpretations of the outcomes, addresses many of the limitations that have been previously identified in the use of computer-based tools for agricultural decision support. The paper further argues that the concepts of resilience and adaptive capacity are useful for the assessment of climate change impacts as they provide an underpinning theory for processes of change in land use systems. The integrated modelling framework (IMF) developed for the simulation of whole-farm systems is detailed, including components for crop and soil processes, livestock systems and a tool for scheduling of resource use within management plans. The use of the IMF for assessing climate change impacts is then outlined to demonstrate the range of analyses possible. The paper concludes with a critique of the IA approach and notes that issues of quantification and communication of uncertainty are central to the success of the methodology.

Keywords: climate change, integrated assessment, simulation, stakeholder deliberation, resilience, adaptive capacity.

Software availability: The Integrated Modelling Framework (collectively called LADSS) consists of commercial software, linked by proprietary and bespoke bridges (see section 3.3). The complete software is not available, however the developers are willing to participate in collaborative development and application. Contact: Keith Matthews, Macaulay Institute, Craigiebuckler, Aberdeen, UK. Tel. ++44 (0)1224 498200, Fax. ++44 (0)1224 311556, email. k.matthews@macaulay.ac.uk

1. INTRODUCTION

By altering a significant component of the biophysical environment, future climate change (CC) may require adaptations to patterns of land use and management. These changes may be required to cope with both an increased incidence of extreme weather events and change in long-term mean conditions. Despite adaptations of current management systems, more radical land use change, involving farm infrastructure may be required. Management systems adaptation to mitigate the impacts of CC is, however, considered the most likely (Easterling 1996). Johnston and Chiotti (2000) are persuasive that decision-making is best studied at the whole-farm scale, which represents the interface between biophysical processes and human intervention through management. Analysis of farm-scale management decisions needs, however, to be given a wider socio-economic context, particularly through considering the influence of public policy measures, markets and supply-chains. Conversely, decisions at the farm-scale have important consequences for environmental protection and landscape quality that need to be considered at larger spatial scales.

Given the wide range of potential consequences of CC it is valuable to explore alternative futures using simulation modelling. Counter-factual experiments can be conducted to better understand the impacts of CC and the possible strategies for amelioration and adaptation. Such analysis enables the assessment of farm system resilience and adaptive capacity. The interpretation of the outputs from such modelling, however, needs to be made by stakeholders since it depends fundamentally on value judgements and requires trade-offs to be made between multiple conflicting objectives. This paper thus proposes an Integrated Assessment

(IA) approach to assessing CC impacts that combines simulation modelling with deliberative processes involving stakeholders.

2. BACKGROUND

2.1 Climate Change Impact Assessment

Various studies have identified potential CC impacts for a range of farm system components, e.g. individual crops at the regional (Southworth et al 2002) and national scale (Holden et al 2003), site-specific cropping systems (Tubiello et al 2000), milk yield and dairy herds (Topp and Doyle 1996), crops and management (Ghaffari et al 2002) and crop yields and ecosystem processes (Izaurralde et al 2003). These studies, and others, provide a range of contrasting interpretations as to potential crop responses under future climate scenarios. Tubiello and Ewert (2002) note that many crop models used in CC studies are not validated against data from elevated CO_2 experiments. Higher temperatures may result in a reduction in yield due to reduced growth period duration, but elevated CO_2 concentrations could counter this (Wheeler et al 2000). Southworth et al (2002) conclude that yields of winter wheat in the US Midwest will be larger, given CO_2 enrichment despite the shorter growing period. Similarly Reilly et al (2003), in a detailed study of CC impacts on US agriculture, concluded that there was an overall benefit, but with large regional variations. At a global scale, Tan and Shibasaki (2003) indicate that the majority of countries, (particularly those in semi-arid areas), will see a reduction in crop yield. It is certain that there will be consequential impacts on livestock systems associated with changes in primary production of feed resources. The form and magnitude of crop responses to CC will not be determined simply by the altered climate and CO_2 concentration, but by localised biophysical conditions as managed by individual farmers, and the capacity for management amelioration or adaptation will depend on the resources available to them.

The studies above, whilst providing valuable insights to components of a farm system, are limited in their ability to determine the consequences of impacts of CC within a farming system with multiple-interacting enterprises. It is important to understand the complexities of inter-relationships within a farm system; particularly as weather events are often the prime driver for the timing and nature of management operations. The resources available and their spatial configuration may also impose particular constraints on adaptation and amelioration strategies that are feasible. To draw conclusion about the impacts of CC on farming systems, it is necessary to integrate the analysis of the biophysical processes and their influence on land use productivity, with socio economic drivers and assess down stream effects.

2.2 Conceptual Framework - Resilience and Adaptive Capacity

Given the wide range of analyses possible within CC impact assessment it is useful to set the analysis in the context of a conceptual framework that can serve to underpin, organise and assist in interpreting the outcomes of the research. One such framework is resilience and adaptive capacity.

Easterling (1996) contrasts short-term system resilience with long-term adaptive capacity. A system with short-term resilience can adapt its operations to maintain existing functionality, absorbing impacts of varying magnitude. Systems with long-term adaptive capacity are able to manage the process of altering their operations, function and appearance to continue to deliver higher-level goals such as food supply or income for land managers, and landscape value. This adaptive capacity is required when change exceeds the short-term resilience of the system. In the former case, for example, increased irrigation capacity may buffer the land use system from changes in the amount or seasonality of rainfall, but if sufficient irrigation water is not available then a change to drought tolerant crops may be required, perhaps requiring investment in new farm infrastructure. Components of the land use systems that give the system its short-term resilience (i.e. investment in irrigation capacity) may thus become factors that constrain the long-term adaptive capacity (i.e. salinisation).

Identification of the limits on a farming system's resilience, the capacity to increase that resilience via changes to management systems and the consequences of such changes, make useful contributions to the assessment of CC impacts. The assessment of farming system's long-term adaptive capacity in the face of CC, however, makes a more significant contribution to the wider debate on the long term sustainability of land use systems.

3. APPROACH AND TOOLS

3.1 Integrated Assessment

The approach proposed within this paper falls within the emerging paradigm of *integrated assessment* and seeks to combine computer-based simulation modelling, using case studies, as part of a deliberative processes. The approach tries to combine the strengths of natural and social science methodologies to better understand the complex planning and policy problems that confront stakeholders and decision makers. The approach is illustrated in Figure 1a. This shows the use of bio-economic modelling using case studies that draw on policy review and macro-scale modelling, to provide materials for workshop presentation and analysis. The simulation modelling being considered within this paper uses an integrated modelling framework (IMF) to simulate the impacts of, and responses to CC at the farm-scale and is detailed in Section 3.2 below. Full details about the framework can be found at LADSS (2005). The deliberative processes allow the research team to elicit many significant factors in determining alternative future scenarios, such as aspirations, expectations, adaptations and practitioner interpretation. The primary outputs from the process are alternative future scenarios that include anticipated decision maker adaptations to policy or environmental change. These alternative future scenarios are subjected to *post-hoc* analysis and can either contribute insights directly, or via a process of generalisation from cases. The outcomes of the process can also generate hypotheses to be tested, or direct inputs to analyses conducted at larger geographic or organisational scales

The approach has evolved from a critical appraisal of development of farm-scale decision-support systems (DSS). Persuasive arguments can be made that the barriers to agricultural and land-use DSS adoption were cost, comprehensiveness, ease of use, sophistication and relevance of the issues addressed. The principal failure of DSS was not however as much technological it was social. DSS developers simply did not account for the social milieu in which their tools would be used. Crucially the developers failed to appreciate that using a computer even if only to “support” a decision would require the decision maker to cede agency to a tool beyond her or his control. Computers are used successfully within land use management, notably in ration management and accounting, but in both cases these are activities in which decision makers have sought the advice or used the skills of other professions. The decision maker in using the tools increases rather than decreases their agency.

Combining simulation modelling with deliberative processes provides a powerful method of addressing policy relevant questions of decision maker adaptation to policy or environmental change and the aspirations of other stakeholder groups (Matthews et al, in press, Hare et al 2002, Meinke et al 2001). The process can be particularly effective in identifying and characterising possible alternative future scenarios. The potentially innovative or surprising nature of these strategies mean that adaptation strategies can be difficult to identify without resorting to unrealistic simplifying assumptions. Since with most controversial decisions the evidence is never self-evident, the deliberative process provides an opportunity to engage in a structured debate focused on the outputs of the analysis. Where multiple perspectives are represented it is possible to elicit contrasting interpretations of the data and to place it in a wider context. Within this discursive process the research team may identify experiential knowledge that can change both model conceptualisations (satisficing, maximising or optimising) and parameterisation (aspiration thresholds or social constraints on management). The deliberative process is not, however, a panacea. Beyond simple stakeholder fatigue the management of expectations from processes and the degree of mutual benefit can be problematic. In most cases participation in such deliberative processes is consultative. The process does not, of it self, resolve issues of influence, representation or empowerment.

The use of case studies as the basis for deliberative processes has been seen to have advantages of grounding the discussion and requiring participants to justify their views against the reality of land management systems. With case studies there is the trade-off between the level of detail provided and how widely one can generalise from results. The level of detail in case-studies seems to be useful in increasing the credibility of models and imposes less of a barrier of abstraction. Land-managers and other stakeholders have proven consistently able to interpret case-studies in the light of their own experience and to draw wider conclusions about their region or sector. These are inevitably more specific for local areas or systems but wider conclusions still provide useful hypotheses for post-hoc testing.

While the modelling framework being developed to support the deliberative processes attempts to support holistic farm-scale analyses, we are not proposing that it is possible to build a single comprehensive model for land use systems. There are important geographic and organisational scales and it is important to have appropriate models operating at all these scales if a full understanding of the system is to be gained. The deliberative process in Figure 1 shows inputs from both social and economic analyses (policy review and macro-economic modelling). These larger-scale analyses set the context for the *status quo* analysis and the impact without adaptation analysis. The deliberative process also shows outputs to larger-scale modelling based analyses. The aim is thus to provide insights from the whole-farm analyses that are useful at larger scales. The linkage in these cases is not between models but between modellers; appreciation of important factors at different scales. Explicitly cross scale modelling is desirable where the intention of the investigation is to determine which factors cross scales and which do not (Gunderson and Holling 2002).

3.2 Integrated Modelling Framework

The structure of the integrated modelling framework (IMF) used for the bio-economic modelling is illustrated in Figure 1b. The core of the modelling framework is made up of the biophysical and management systems models. These are primarily driven by farm-scale bio-physical and management regimen data, though they also reference meso- and macro scale data such as market prices for inputs and sales. The accounting framework defines views on the state variables of the system being simulated. The accounting framework thus presents a coherent and organised view of the state information that may have a particular theme, such as financial (gross/net margins or cash flow) or physical accounting (N balance or net greenhouse gas emissions). Beyond the accounting framework are tools that support particular forms of analysis, these can be simply presentational, more sophisticated as visualisation or more complex such as multi-objective land use planning, cost-benefit analysis or sustainability assessment.

The biophysical and management systems models are differentiated here, though in reality most systems models can consider both aspects, since conceptually the rate variables within the biophysical models do not depend on decision maker preferences or other normative data. Examples of biophysical systems models include crop growth which, where water or nutrients are not limiting, is governed by solar radiation and temperature, or livestock systems where maintenance requirements are determined by size and activity levels. Management systems models determine the effects of, and constraints on, management interventions such as rates of fertiliser application or stocking rates. This conceptualisation tries to differentiate the management levers since constraints on these may be financial or social.

The bio-physical systems models within the framework are CropSyst (Stöckle et al 2003) and a bespoke livestock systems model (LSM). CropSyst is a multi-crop simulation model that estimates production (yield) and environmental parameters (water balance, N and OM status etc.) for a wide range of crops and crop rotations under different management regimen (Figure 1c). CropSyst was chosen from a review of alternative crop models since it provides a conceptually unified modelling system for many crops minimising the dangers of structural uncertainty in making cross crop comparisons. Novel crops, i.e. bio-fuels or GMOs can be modelled, where parameterisation is possible, permitting exploration of alternative forms of land use. CropSyst also has data requirements that can reasonably be met and provides assisting utilities to substitute for missing parameters based on well established procedures (e.g. using pedo-transfer functions to derive soil hydrological parameters).

The LSM is an energetics based livestock growth model that tracks the state of cohorts of ruminants (to date cattle and sheep), as they progress from birth through weaning and growth to finishing for market. The definition of the herds through which cohorts progress, the linkages between herds and the management decisions required, are implemented using a graphical programming toolkit. Intake requirements for specified diet are estimated for each cohort and stocking rates set to be consistent with materials available in the fodder pool, that is made up of on-farm (modelled within CropSyst – Figure 1c) and bought in materials. The interactions between grazing stock and pastures are simulated using daily clipping events whose magnitude is set by the LSM. The enhancement of the CropSyst clipping event to better represent grazing by stock has been developed in partnership with the CropSyst development team.

The quality of analyses will depend on the quality of farm- and meso/macro scale input data, but the biophysical and management systems models have been chosen, if not to minimise data requirements, then to depend on a small number of relatively easily measured parameters. The framework is robust in the face of missing data with the ability to substitute either experiential or standard published figures. This does, however, clearly restrict the range of analyses possible. The models are, where possible, calibrated and validated against onsite data, and if this is not possible then parameterisations based on regional data or similar sites. Un-calibrated or non-validated outputs are flagged and used only as indicative of trends.

The management systems model within the IMF is the resources scheduling tool (RST) (Matthews et al 2003). The RST is a heuristic based scheduler that determines the utilisation of on farm-resources such as labour and machinery, based on tasks generated from patterns of land use and the livestock management regimen. The RST can also assign machinery intensive or specialist tasks to contractors where appropriate. The outputs from the RST are used in determining the fixed costs for patterns of land use and management.

The deliberative support aspects of the IMF are higher-level tools that make use of the functionality provided by the biophysical and management systems models and the accounting framework. These tools support the deliberative process by presenting in a structured way a range of options to decision makers or stakeholders. These serve as *marketing planning* tools, defining a set of alternative states with estimated properties. The options presented may serve as the basis for plans with further customisation by decision makers to reflect their preferences or factors not considered by the tools, or can be used as part of an iterative process of evaluation. The tools developed to date have focused on spatial allocation problems and finding patterns of land use that achieve the best possible balance between multiple objectives. The outputs from these tools are typically a set of Pareto-optimal solutions that define the trade-off between objectives (Matthews et al, in press).

Whilst the IMF can consider a wide range of environmental and policy consequences it is not comprehensive. It is not yet possible to assess animal welfare and consequential labour requirements, crop quality with its implications for market value or feed for livestock, nor the potential impacts on the prevalence of pests and diseases in both plants and animals. Such omissions may, however, be considered qualitatively through the deliberative process. Structurally the IMF has limitations on the degree of integration between its sub-systems. For example, it is not possible to adaptively adjust stocking rates in response to grazing availability within a single simulation of pasture growth. This can be significant as the grazed pasture’s growth is a function both of agro-climatic conditions and the imposed grazing regimen. The grazing regimen determined by the LSM defines one of the management parameters for the CropSyst simulation. Any adjustments to the grazing regimen must be made at the completion of the CropSyst run using the diagnostics provided and a further CropSyst simulation made. A further limitation of the IMF is that while simulations are spatially explicit, in that they are conducted on a field-by-field basis, the component models are not distributed and thus cannot not take account of lateral flows (which can be significant for soil-water regimens) or changes in the influences of surrounding fields (such as shading or shelter) during the course of a simulation. Investigations into modelling approaches separating state from rate variables and spatially distributed methods are ongoing.

3.3 Implementation

The IMF is implemented, where possible using commercial software-tools. While this has cost implications for making software available to third parties, it minimises the overhead of software engineering and maintenance and allows the development team to take advantage of the continuing refinement and increased functionality of the systems.

The core of the IMF is the ORACLE relational database. This is the common data store, referenced by all the components of the IMF, CropSyst, the LSM and the RST. The database holds all the biophysical, management regimen, infrastructure and scenario data, apart from any geometric data that is held in a geographic information system (GIS)(GE Smallworld Core Spatial Technology). All the simulation model components (except CropSyst), the management systems models and the accounting framework are implemented in Gensym G2. This is a flexible software development environment that facilitates implementation of declarative, procedural, object based or visual programming code and has a wide range of layered applications to assist with interfacing to other software systems and developing GUIs. G2 links to ORACLE via a proprietary software bridge and to GE Smallworld via a bespoke bridge. The current implementation runs on a Sun/Solaris UNIX platform but can be ported to either Microsoft or Linux platforms as required. The CropSyst software used is essentially version 4, but ported to run on UNIX and modified to read and write data to ORACLE and with a new GUI built in G2.

4. Utility of Integrated Assessment for Assessing Climate Change Impacts

4.1 Case-Studies and Issues

The IA is being developed using two case studies, one in upland Scotland the other in Italy. The two land use systems face contrasting challenges from CC, but face the same issues of resilience and adaptive capacity.

Hartwood Farm is a 350 ha mixed cattle (c. 200) and sheep (c. 500) system, representative of marginal production areas in Scotland. It is characterised by cold, wet and windy winters and cool moist summers. Soils are typically poorly drained gleys with significant limitations on trafficability and susceptibility to poaching by livestock. The predominant land use is rye grass pasture and silage production. Winter wheat and spring barley is grown as whole crop fodder. The direct effect of CC will be seen in its effect on pasture and conserved fodder growth in terms of quantity, quality and timing. Increased rainfall (particularly in Spring or Autumn) that restricts machinery operations or livestock access to grazing may have significant effects on the financial viability of the systems as currently constituted (Cooper et al 1997). Indirect effects via increased incidence of livestock disease are also possible.

Agrichiana farm in Tuscany, is a 300 ha combined cropping and indoor reared beef system, with cool moist winters and warm dry summers. The farm has soils artificially deepened in the past by flooding from nearby rivers and canals. Semi-permanent and permanent water bodies make up 10 hectares of the farm, providing reservoirs for summer irrigation. Crops grown include: cereals (durum wheat), forages (alfalfa, triticale), oil-seed (sunflower) and horticultural (capsicum, tomato), root (sugarbeet) and leaf crops (tobacco). A significant area is used for ‘set-aside’ (non-productive areas which currently receive subsidies). Livestock activity is the breeding of Chianina cattle (c. 300 animals). The primary issue of concern is meeting summer irrigation demand (Holden et al 2003, Izaurralde et al 2003). While there are engineering solutions to increasing the volume of water available these have both financial implications (capital and operational costs) and environmental uncertainties (is the winter flow in the catchment sufficient to meet the increased demand?). Secondary, though still serious concerns, include the seasonality and intensity of rainfall that can effect both crop establishment operations and the quality of yield. Changes to the cropping systems may have implications for the viability of the associated livestock enterprise.

A further benefit of using case studies is that back-cast climate model output can be compared with observed historical data for a particular location, to determine statistical similarities and differences. Observed and estimated climate model back-cast weather data, when used within the land use models, helps identify the uncertainty that the modelled data may introduce. This is an important step as it helps to put into perspective the results gained from future climate prediction data.

4.2 Climate Change Scenario Characterisation

The weather data requirements for the CropSyst models are daily precipitation, maximum and minimum air temperature and solar radiation. These can be met from a number of sources: Global Circulation Models (GCM), statistical downscaling models, regional scenarios or stochastic weather generators (Figure 1c). Data can be further manipulated to investigate particular weather events or event frequencies. Atmospheric CO_2 concentration levels can be set in CropSyst representative of the time period and CC scenario, for example the IPCC scenarios for UK (IPCC 2000). Whatever the source of the CC scenario the uncertainties in prediction mean that definitive conclusions should not be drawn, but rather a scenario testing approach adopted.

Characterising alternative CC scenarios in ways that are meaningful to stakeholders is an essential first step in allowing the potential impacts on systems resilience and possible adaptations to be assessed. Elementary statistics (mean, median) and distribution probabilities applied to weather variables such as rainfall, reference evapotranspiration and air temperature are useful, but their significance can be difficult for stakeholders to interpret. The IMF derives agro-meteorological metrics based on those of Bellocchi et al (2004). Since in northern hemisphere temperate climates most crop growth occurs between January-June, the accumulated temperatures above 0°C occurring in the first semester of the year can be used to compare potential for crop growth. The Fournier index (FAO/UNEP 1977) and seasonality index (Walsh and Lawler 1981) help assess the inter-annual variability of rainfall distribution. A simplified soil water balance making assumptions on soil characteristics (Francis 1981) allows assessments of excess winter rainfall (which may be required for irrigation reservoir recharge), access periods for machinery or grazing and summer soil moisture deficits (maximum summer deficit or number of days with air-dry soil). Presentation of the metrics as differences from the current climatic regime is also helpful in aiding stakeholder interpretation.

4.2 Individual Enterprise Responses

For a given CC scenario, CropSyst estimates the yield and environmental consequences for combinations of crop, soil and management for individual years or a part of a crop rotation (Figure 1c). Variations in the quantities of weather variables and their timing and event frequency will impact on a number of physiological components. Higher mean temperatures increase the rate of phenological development, but reduce the amount of time for biomass accumulation. Solar irradiance levels partially determine the rate of biomass accumulation. Altered precipitation impacts on soil hydrological process, with corresponding changes to nitrogen and other nutrient balances, as well as plant water availability and accessibility. Higher temperatures give a faster nitrogen turnover, with more precipitation giving greater leaching and runoff. These impacts do not happen in isolation from each other and all have potential to impact on the resilience of the cropping systems. Additional risk may be incurred for a given set of CC weather variables, producing conditions that restrict establishment, or increase physical damage, such as desiccation (high temperatures and low precipitation) or lodging (high temperatures giving rapid growth plus higher precipitation and wind giving wet soil and physical movement). Observations of the frequency of such events beyond defined thresholds (such as 1 in 5 years), indicate when the physical impacts of CC may exceed acceptable tolerances for individual enterprises. Hence vulnerability of enterprises and subsequent impacts on whole farm resilience can be explored should the frequency increase (i.e. 2 in 5 years). Linkages can thus be identified between initial biophysical impacts and possible socio-economic responses. Alternative amelioration strategies for the impacts identified may be assessed using changes to the management regimens defined for each crop.

For livestock based enterprises potential stocking rates, herd sizes, turnout and housing dates etc, may be significantly changed by CC. Changes in on-farm produced fodder crop quantity may occur with an associated impact on feed quality. Increased biomass production reduces the need for feed supplements, if quality is still sufficient, raising the potential for larger herds. The opposite implies higher costs and/or reduced herd size. Higher temperatures may lead to additional silage cuts being made, but also possibly reducing the individual biomass yield per cut, due to the accelerated phenological development and corresponding shorter period for biomass accumulation. These results can indicate the potential for changing fertiliser applications and the balance between areas allocated to silage and pasture. Changes to the temporal availability of feed resources and weather conditions may facilitate a shift in the management of animal reproduction, i.e. an autumn to spring calving system.

4.3 Farm-Scale Socio-Economic and Stakeholder Interpretation

The best developed of the whole farm assessments are the financial metrics. These metrics provide the key means of assessing whole-farms systems as businesses and of assessing effects (positive or negative) that changes in policy (via support payments or regulatory measures) can have on land manager's adaptation strategies. The metrics include both gross margins (income minus variable costs) and net margins (gross margins minus fixed costs). Other financial interpretations such as returns on investments can be implemented based on the data held in the IMF accounting frameworks. The interpretation of such financial metrics does, however, require consideration of the wider socio-economic circumstances and ideally stakeholder interpretation. The likelihood and probable success of adaptation strategies in the face of CC and policy change will depend on such interpretations.

The anticipated size and value of markets and access to those markets via intermediaries in the food chain are key factors in the determining the feasibility of alternative land use strategies. Thus the resilience and adaptive capacity of particular systems depends on an understanding of processes operating at wider geographic and organisational scales. For the purposes of modelling individual whole-farms these may be treated as external drivers but linkage with sectoral modelling and analysis of trends in international trade and consumer preferences is necessary.

While some issues of socio-economic interpretation can be addressed by linkage to research at other scales a strong case can be made for stakeholder interpretation of potential outcomes. Take for example the net-farm income metric. Beyond the assumptions inherent in this metric, (and the accounting conventions for apportioning fixed cost may be quite unsuitable for the circumstances of particular businesses), careful interpretation is still required. Is the assumption of standard wage rates reasonable for owner family farms? As an objective measure, relative to statutory norms, perhaps it is, but it does not capture factors central to the resilience of the land use systems. Do land managers set their aspirations below maximisation of profit if this reduces the risk to their survival when faced with unknowable climatic and uncertain commodity price futures? Does this risk-reduction strategy decrease the adaptive capacity of the system (as defined by its ability to generate income for reinvestment) while increasing resilience? Does the availability of rent-free housing or land on which to erect a new dwelling and the skills to construct it mean that the value of the cash wage could be much greater than apparent? What does a rate of labour utilisation of 50% mean? Is it chronic underemployment or an opportunity to pursue a contracting business or employment outwith the agricultural sector? This will to a great extent depend on the wider geographical circumstances of the farm. What assumptions are being made about pluriactivity, who is undertaking of-farm activity, how does it contribute to or limit the land management regimen? All these issues can have profound effects on the resilience of systems of land use that would cease to exist were decisions made rationally on the basis of profit maximisation.

These issues take the whole-farm analysis of resilience and adaptive capacity in the face of CC and situate them within the wider issue of sustainable rural development. Multiple-perspective appraisal via a deliberative process is a useful means of providing new information to stakeholders and generating dialogue around its interpretation. The use of the information provided by stakeholders is beyond the control of researchers and falls within the political processes of representation and governance.

5. Critique of the Approach and Tools

While the IA approach of combining simulation modelling with deliberative processes looks likely to provide useful insights into the resilience and adaptive capacity of land use systems faced with climate change there remain significant scientific and practical challenges.

5.1 Uncertainty –Sources and Strategies

It is arguable that the principal limitation of the approach proposed for assessing CC impacts is that the uncertainty in the model estimates is either unquantified or so large that meaningful conclusions cannot be drawn from them. This is particularly true for estimates of resilience and adaptive capacity for farming-systems since weather is a primary driver and estimates of alternative future climates derived from GCM's have significant uncertainty, particularly for precipitation (Murphy et al 2004). Weather data sources can introduce substantial levels of uncertainty to model estimates (Rivington et al 2003). The uncertainties and systematic biases in input data are propagated by and possibly magnified by uncertainties in biophysical processes models and compounded in socio-economic analyses by uncertainties in policy and macro-economic systems. There is therefore the need to devote significant effort within the simulation modelling aspects of IA, where possible and cost-effective, to improve the quality of input, calibration and validation datasets and, in any case, to make efforts to quantify the uncertainties in simulation model outputs and identify their source. Methods for analysing the operation of simulation models are increasingly being developed within the statistics literature.

While such methods provide the tools to objectively quantify the uncertainty, employing and communicating the nuances of such information may still present a challenge. Uncertain results, while the current best estimate, do not fit well with popular notions of scientific fact and certainty. This can be particularly awkward when dealing with controversial issues such as CC that may result in policy decisions with impacts across society. Uncertainty can leave room for unscrupulous sceptics or representatives of vested interests to make best-case interpretations that allow for business-as-usual rather than supporting precautionary responses. It is therefore essential that the probabilities associated with alternative outcomes be presented. The process of stakeholder engagement, via deliberative processes with adequate opportunities to communicate both the insights and limitations of analyses, seems to provide the best means of ensuring an adequate debate. The presentation of model results as part of the deliberative process may also be seen as a form of expert validation. If the model outputs are unacceptable and rejected as part of the stakeholder review, then the process cannot continue and further modelling work has to be undertaken until acceptance is reached.

5.2 Other Limits

Combining CC with socio-economic scenarios can generate numbers of alternative futures that are both computationally infeasible to evaluate and difficult to communicate convincingly to stakeholders. Again the process of engagement with stakeholders from differing perspectives provides a means of prioritising scenarios and developing coherent narratives possessing a clear internal consistency. This is likely to be a iterative process with cycles of counterfactual analysis on particular issues increasing the mutual understanding of the issue. The success of such a process may, however, be limited by the time which stakeholders, can devote to such activities, or by the time limits on consultation and deliberation periods.

The combination of CC with socio-economics also raises the issue of incompatible timescales, with socio-economic change (particularly for public policy) happening at rates greatly in excess of CC. The interactions of slow and fast change variables have, however, been seen to result in surprising outcomes and rapid phase changes when thresholds are breached, overcoming the resilience of existing systems. Simulation methods based on the concepts of Panarchy (Gunderson and Holling 2002), which concentrate on the interactions between processes operating at different spatial and temporal scales, seem to have promise in addressing these issues.

Finally the approach is limited by the functionality of the simulation models available. An integrated and flexible modelling framework populated by components prioritised by stakeholders is able to address a wide range of questions, but does inevitably restrict the range of questions that may be addressed. Our experience is, however, that stakeholders and decision makers are able to draw conclusions beyond the strict functionality of the model. One possible approach to increasing the flexibility of models while not necessarily increasing their complexity, is a component based modelling framework with a small central processing core that links, as required, independent modules that represent t processes.

From the presentation of the approach and its critique it is clear that while there are technical and scientific challenges in assessing the impacts of CC, the challenge is in managing the deliberative processes such that the research is credible and relevant. The integrated assessment approach combining simulation modelling with deliberative processes addresses many of the limitations of previous approaches, ensuring rigorous analysis is focused on issues of relevance to stakeholders and decision makers.

7. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the funding support of the Scottish Executive Environment and Rural Affairs Department, the British-Italian Partnership Programme for Young Researchers (British Council, Ministero dell'Istruzione dell'Università e della Ricerca, CRUI). The authors are also grateful for the assistance provided by Mr G. Corsar of Hartwood farm and Dr Ciuffi, Agrichiana Farming.

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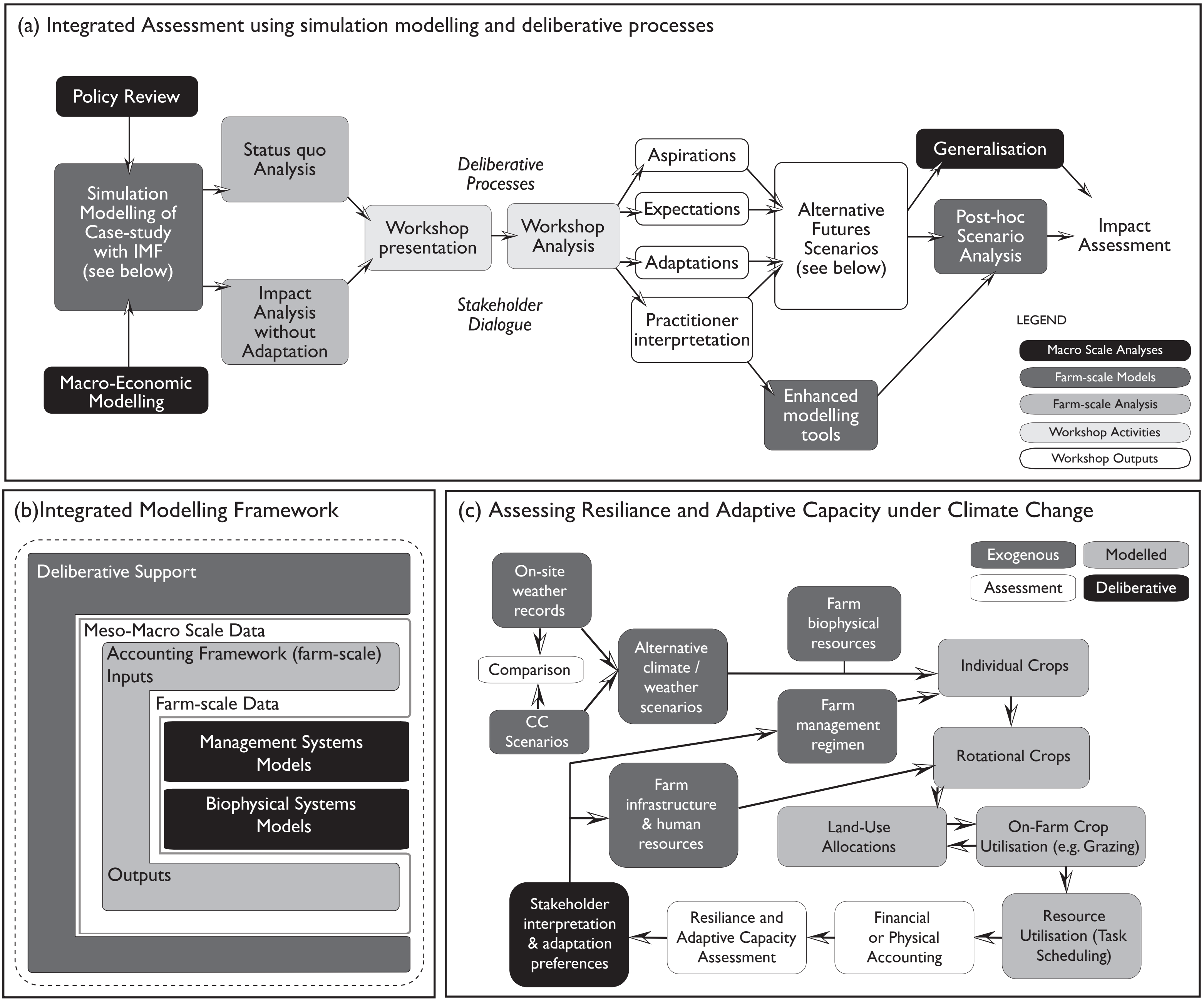
Caption headings:

Figure 1. Processes and tools for the Integrated Assessment of climate change impacts



(a) Integrated Assessment using simulation modelling and deliberative processes
Policy Review
Simulation Modelling of Case-study with IMF (see below)
Macro-Economic Modelling
Status quo Analysis
Impact Analysis without Adaptation
Deliberative Processes
Workshop presentation
Workshop Analysis
Stakeholder Dialogue
Aspirations
Expectations
Adaptations
Practitioner interprtetation
Alternative Futures Scenarios (see below)
Enhanced modelling tools
Generalisation
Post-hoc Scenario Analysis
Impact Assessment
LEGEND
Macro Scale Analyses
Farm-scale Models
Farm-scale Analysis
Workshop Activities
Workshop Outputs
(b)Integrated Modelling Framework
Deliberative Support
Meso-Macro Scale Data
Accounting Framework (farm-scale)
Inputs
Farm-scale Data
Management Systems Models
Biophysical Systems Models
Outputs
(c) Assessing Resiliance and Adaptive Capacity under Climate Change
Exogenous
Modelled
Assessment
Deliberative
On-site weather records
Comparison
CC Scenarios
Alternative climate / weather scenarios
Farm biophysical resources
Farm management regimen
Farm infrastructure & human resources
Individual Crops
Rotational Crops
Land-Use Allocations
On-Farm Crop Utilisation (e.g. Grazing)
Resource Utilisation (Task Scheduling)
Financial or Physical Accounting
Resiliance and Adaptive Capacity Assessment
Stakeholder interpretation & adaptation preferences