Perennial Energy Crops: Implications and Potential

Angela Karp¹, Alison J. Haughton¹, David A. Bohan¹, Andrew A. Lovett², Alan J. Bond², Trudie Dockerty², Gilla Sünnerberg², Jon W. Finch³, Rufus B. Sage⁴, Katy J. Appleton², Andrew B. Riche¹, Mark D. Mallott¹, Victoria E. Mallott¹, Mark D. Cunningham⁴, Suzanne J. Clark¹b and Martin M. Turner⁵

¹Centre for Bioenergy and Climate Change and ¹b Centre for Mathematical and Computational Biology, Rothamsted Research, West Common Harpenden, Hertfordshire, AL5 2JQ, UK; ²School of Environmental Sciences, University of East Anglia, Norwich, NR4 7TJ, UK; ³Centre for Ecology and Hydrology, Maclean Building, Benson Lane, Crowmarsh Gifford, Wallingford, Oxfordshire, OX10 8BB, UK; ⁴Game and Wildlife Conservation Trust, Fordingbridge, Hampshire, SP5 1EF, UK; ⁵Department of Geography, University of Exeter, Laver Building, New North Road, Exeter, Devon, EX4 4QE, UK

[a]Introduction

Policy interest in perennial energy crops such as short rotation coppice (SRC) willow and Miscanthus grass is firmly established in Europe, and the UK government has strongly supported the use of biomass crops as a source of electricity, heat and even transport fuel. The UK Biomass Strategy envisages a major expansion in both the supply and use of biomass, which is seen as playing a central role in meeting the EU target for renewable energy. There are various drivers of this policy interest, notably the potential of biomass as a low carbon energy source in response to the challenge of climate change, the need to improve energy security and the desire to strengthen rural economic development in the context of agricultural decline. From a land-use perspective, the prospect of diverting a significant proportion of farmland principally from food production to energy production would
represent the most fundamental change in land-use since the decline of horses as the primary source of power in agriculture, and a significant source of power for general transport, during the first half of the twentieth century.

This chapter considers the range of potential impacts of increasing rural land-use under perennial energy crops, drawing on environmental, social and economic research to provide a broad-based assessment. The use of farmland for perennial energy crop production on the scale envisaged will have potentially far-reaching implications for biodiversity, hydrology, landscape and the rural economy. This chapter not only explores the research evidence for the nature and scale of these effects, but does so in the context of the use of Sustainability Appraisal (SA) as a tool for land-use planning. In particular, this review will identify the scientific tools which should underpin the conduct of Environmental Impact Assessments (EAIs), Strategic Environmental Assessments (SEAs) or SAs where strategic decisions on the planting of such crops have to be made.

[a]Background

Global warming and energy security are high on the agendas of nations world-wide. The impacts of climate change, rising fuel costs and concerns over future energy security already affect the everyday lives of people and technological solutions are urgently sought. Producing feedstock from crops as renewable sources of carbon for conversion into heat and power (bioenergy) and liquid transport fuels (biofuels) has the potential to provide promising solutions from the agricultural sector. Biofuels, in particular, have been heralded as “green gold” providing a renewable resource that could mitigate global climate change, promote energy security, and support agricultural producers around the world (FAO, 2008).
The UK is a signatory of the Kyoto Protocol (United Nations, 1998) which aims to reduce global CO₂ emissions, and in 2000 set a target that 10% of UK electricity supply should come from renewable sources by 2010. The most recent Energy White Paper included an aspiration to double this proportion to 20% by 2020 (DTI, 2007). Several recent strategy and policy documents confirmed the potential of biomass as an energy source (RCEP 2004; Defra, 2004; DTI and Carbon Trust, 2004) and a number of practical measures are now in place to support expansion including planting grants, the UK Government’s Defra Bio-energy infrastructure scheme and the Renewables Obligations for licensed electricity suppliers (ROs) and transport fuels (RTFO). The UK has also committed itself to reducing greenhouse gases by 80% compared to 1990 levels by 2050 with a strategy to achieve this which includes support for small-scale renewables and encouraging renewable heat (Department of Energy and Climate Change, 2008).

Within a short time frame of recognising the potential of bioenergy and biofuel crops, however, there have been increasing counter-concerns over the potential implications for two other globally recognised future challenges: food security and water availability. Agricultural commodity prices have risen rapidly and governments have been alerted to the indirect consequences of growing energy crops on displacement of land for food production, as well as the failure of some biofuel chains to achieve positive carbon balances and significant greenhouse gas (GHG) reductions (The Royal Society, 2008; Gallagher, 2008; Searchinger et al, 2008; FAO, 2008).

The UK Government and the EU remain committed to including energy from crops in the renewable energy portfolio but emphasis has become sharply focused onto the development of sustainable bioenergy and biofuel chains, which includes producing energy from crops that can be grown on sub-prime arable land to reduce competition with food production. Perennial
biomass crops have the potential to offer sustainable bioenergy production that fits these criteria (Karp and Shield, 2008). As perennials, they recycle the major proportion of their nutrients, require fewer inputs and thus have the potential to be grown on lower grade land. Life cycle analyses of fuel chains for these crops also indicate higher energy gains and greater GHG reductions than those associated with “first generation bioenergy crops” (Rafaschieri et al, 1999; Adler et al, 2007; von Blottnitz and Curran, 2007).

There are two types of perennial energy crops currently envisaged for UK farmland: coppiced trees and grasses. Of these, the most advanced agronomically and, in terms of plantings, the most common, are shortrotation coppice (SRC) willow (Salix spp) and Miscanthus grass (Miscanthus x giganteus). SRC willow and Miscanthus have particular advantages as energy crops. Unlike annuals, there is no annual cultivation cycle, which improves the energy and greenhouse gas balance, and compared with other perennials they are fast growing, with the potential to produce large yields from low inputs of fertilisers and pesticides. Government incentives have been introduced to encourage establishment of biomass crops (e.g. the Energy Crops Scheme, ECS, www.naturalengland.org.uk/planning/grants-funding/energy-crops/default.htm). These have led to a recent increase in the area of land under SRC willow and Miscanthus and, for example, between 2001 and 2007, approximately 7,450 ha were established under this scheme in England alone (see statistics at www.nnfcc.co.uk).

Whilst the potential benefits of growing perennial biomass crops for renewable energy are clear, conversion of large areas of land to SRC willow and Miscanthus could constitute a major land-use change, depending on the land-use they replace. In particular, they are physically different and are managed differently to arable crops currently grown in the UK. They are in the ground for 7-25 years; although Miscanthus is harvested annually in early
spring, harvesting cycles for willow are every 2-3 years in winter. The crops are also very tall (3-4 m) and dense, and deeper rooting than traditional arable crops. These factors have potential implications for the appearance of the rural landscape (Figure 1), tourist income, farm income, hydrology and biodiversity.

**Figure 1** SRC willow (left) and Miscanthus (right) are very different to crops traditionally grown in the UK

A number of research investigations have been conducted to assess the impacts of perennial biomass crops (see Rowe et al, 2008 for recent review, and below). Most studies have concentrated on specific economic or environmental impacts, such as on economic viability, hydrology or biodiversity. Some have suggested how assessments of impacts should be made (e.g. Firbank, 2008 for ecological impacts). Very few, however, have tackled how the different social, economic and environmental impacts could be assessed in an integrative way or how evidence relating to negative or positive impacts should be utilised in decision-making and land-use planning.

The RELU-Biomass project (www.RELU-Biomass.org.uk) funded as part of the UK Rural Economy and Land Use (RELU) programme recognised that targeted scientific research was needed to provide a science-based integrated evaluation of the social, economic and environmental impacts of perennial biomass crops. To achieve this, during three years (01/01/06-31/12/08) RELU-Biomass brought together scientists of the main disciplines to review existing information and also conduct new specific research activities to help fill knowledge gaps. Social science research, including GIS-based approaches, was carried out by the University of East Anglia, economic studies by the University of Exeter, hydrological...
studies by the Centre for Ecology & Hydrology (CEH) and biodiversity studies by Rothamsted Research and the Game & Wildlife Conservation Trust. DEFRA funded a complementary project on biodiversity, which enabled size of field, age of crops and also bird use of Miscanthus to be investigated. Two contrasting farming systems typical of different regions of England (Figure 2) were chosen as the main study areas: (i) the arable cropping dominated system as represented by the East Midlands; and (ii) a grassland-dominated system typified by the South West of England.

**Figure 2 English regions**

These two regions also have contrasting environmental characteristics (e.g. more rainfall in the South West) and, with Yorkshire and the Humber, contain the main concentrations of the 15,000 plus ha of energy crops currently planted in England.

Two basic approaches to integration were taken: a GIS-based constraint mapping exercise and the development of a Sustainability Appraisal (SA) framework as a decision tool for land-use planning. The latter involved direct stakeholder engagement and the project also benefited greatly from an Advisory Committee of principal stakeholders. Specific objectives were to: (i) develop an integrated scientific framework of the medium and long term conversion of land to energy crops; (ii) evaluate the implementation of the SA framework and identify the most appropriate planting scenarios; (iii) apply an integrated scientific approach to update existing Best Practice Guides for planting short rotation coppice (SRC) willow and Miscanthus at any scale and (iv) provide the scientific tools to underpin the conduct of EIAs, SEAs or SAs involving projects, policies or programmes where increased planting of energy crops is proposed or anticipated.
In the sections that follow, we first describe the approach taken in the different disciplines in the RELU-Biomass project and provide some of the results achieved so far. We then describe how these data are being integrated into tools for decision-making and land-use planning. Finally, we conclude by commenting on the implications and future potential of perennial biomass crops in the light of the findings so far.

[a] Filling in evidence gaps: disciplinary research on impacts in RELU-Biomass

[b] Public attitudes to renewable energy and visual impact

Best Practice Guides and Guidance Notes are available for both energy crops, which include siting considerations and plantation management protocols that are designed to address visual impact (as well as biodiversity and hydrological considerations) but these are usually at the site level (DTI, 1999; Defra, 2001; 2002, Bell and McIntosh, 2001). In RELU-Biomass, it was considered important to move from site to landscape-scale assessments of planting schemes and evaluate different means of communicating information on potential impacts to the public and other stakeholders.

One valuable framework for assessing the visual impacts of increased energy crop planting in different parts of England is provided by the set of Joint Character Areas (JCAs), defined by the Countryside Agency, English Heritage and English Nature in the mid 1990s. There are 159 JCAs, each with a description of what makes it distinctive, how this character arose and potential future management issues. These areas have since been used for various planning and management purposes, including judging the capacity of landscapes to absorb different amounts or types of change). Several recent studies have used this framework to assess the
suitability of areas for planting of energy crops, including work in the South West by Capener et al (2004) and the national opportunities mapping exercise for energy crops in England sponsored by Defra (Defra, 2006). These issues of landscape sensitivity were incorporated into the GIS constraint mapping study described below in the section on Integrative Approaches.

A questionnaire survey was conducted during the summer of 2007 in town centres within the East Midlands and South West where SRC and Miscanthus are grown in the surrounding areas to assess current awareness and opinions of the general public regarding energy crops. Two urban centres (one larger and one smaller in size) were selected for survey in each region. These were Lincoln and Retford in the East Midlands and Taunton and Bridgwater in the South West. The content of the questionnaire was designed to be conducted in the street and therefore needed to take no more than about five minutes. Most of the questions involved selection from a set of possible responses and sets of photographs were used to show the appearance of SRC, Miscanthus and a biomass power station. The answer choices and photographs were contained in a booklet which was given to respondents while the survey was conducted. These questions and the booklet layout were street tested in a pilot exercise in advance of the main survey. Overall, 490 completed questionnaires were obtained, with an acceptable age and gender balance compared to census statistics for each centre.

The results of this questionnaire survey indicated that there were many positive public attitudes towards planting of biomass crops as a renewable source of energy. For instance, over three-quarters of respondents said they thought SRC and Miscanthus would fit very or reasonably well into the landscape of their local area. Over 60% of survey participants also said that they would not mind seeing the crops within the view from their home. However,
showing participants a photo of a biomass power station and stating that this would need to be located within e.g. 25 miles had a distinct impact on responses with the percentage saying they would not mind having the crops within the view from their house dropping below 30%. This suggests that it is issues of infrastructure, particularly the scale of energy generation, rather than landscape or other concerns, that will need to be addressed if public support for biomass crops is to be developed. These matters are currently being examined further through a number of focus groups and discussions with regional stakeholders.

A third approach used in this part of the project was the development of GIS-based computer visualisations of energy crop plantings in specific locations within the study regions for use as a visual tool in stakeholder and public consultations. For example, Figure 3 shows a simulated view along a road in Lincolnshire before and after the planting of Miscanthus. Interactive real-time models have also been created to run on an Elumens VisionStation and have been used at a number of public events (Figure 4). These visualisations were used at the focus group meetings to assess the visual impact of different management options (e.g. size of field margins) and opinions on the public acceptability of various scales and distributions of energy crop planting in different landscape settings.

**Figure 3** Visualisations showing view a) prior to Miscanthus planting and b) with a mature crop.

**Figure 4** Visualisation display at the British Association Festival of Science, York, September 2007
Biodiversity

Only limited research has been carried out in the UK, or elsewhere in Europe, on wildlife use of *Miscanthus* (Semere and Slater, 2005). In contrast, for SRC willow, several studies have been undertaken. Early non-commercial plantings in the UK were found to provide new habitat opportunities for a variety of wildlife. Plant diversity consisted of a mixture of pre-existing and colonising plants (Sage, 1998; Cunningham et al, 2004). Although some research has been directed at ground-dwelling species (Coates and Say, 1999), invertebrate studies have mostly focussed on the crop canopy, where a variety of herbivorous and phytophagous invertebrates have been recorded including some pests (Sage and Tucker, 1997; Sage, 2001). For birds, assessments suggest SRC supports some species not normally found in intensively managed arable crops and others that are. Comparisons indicated that fields of harvested SRC contain arable and grassland birds in addition to scrub and woodland species, leading to a net conservation gain (Sage and Robertson, 1996; Sage 2001).

In RELU-Biomass an extensive study has been carried out of biodiversity in 16 fields each of established *Miscanthus* and willow SRC plantations using the approaches developed for the Farm Scale Evaluations (FSEs) of genetically modified, herbicide-tolerant crops (Firbank et al, 2003; Haughton et al, 2003; Heard et al, 2005; Bohan et al, 2005). Although the two study regions did not provide sufficient sites, sampling was achieved across both the ‘Easterly’ and ‘Westerly’ lowland Environmental Zones of Great Britain (see Haines-Young, 2000). The complementary DEFRA-funded project extended the total number of fields sampled to 24 per crop. As with the FSEs, sampling was limited to weed plant and invertebrate species that can be sampled relatively easily (Firbank et al, 2003). At each site, twelve, 32m long transects were evenly distributed around the edges of the crops, and ran perpendicular to the crop edge into the crop. Weed species were counted within quadrats at
five sampling points along each transect, on two standardised dates over the season, with samples of weed biomass also being taken at the final species count. Monthly weed-seed rain samples were collected from two points along four of the transects. Vortis suction sampling was conducted for plant and soil-surface dwelling invertebrates, at three points along four of the transects on two dates within the season. Sticky traps were placed within the crop and in the canopy at three points along four transects once during the season to assess flying invertebrates. Bees and butterflies were counted along four line-transects of 100m that ran along the external edges of the crop (headlands), monthly during the season to assess foraging behaviour.

A rich data source is being generated from this project, only a portion of which has been analysed at the time of writing. Together with existing data on the abundance and diversity of plants and invertebrates in conventional arable management from the FSEs and existing long-term invertebrate and plant species lists for arable (LINK-IFS), grassland and woodland systems, these data will allow: (i) the risks for species diversity and abundance to be evaluated and appropriate criteria for power and sample size follow-up testing to be set; ii) the biodiversity associated with socially/aesthetically acceptable cropping to be estimated; and iii) predictions for the optimum balance between biodiversity and the costs of cropping to be made for each crop and environment.

Here we present data for the butterflies in headlands of Miscanthus and SRC willow crops compared with the arable crops of the FSEs. For butterfly family groups and total butterflies, year totals per km of transect walked were calculated for each FSE site (0.3 km per visit, and between one and seven sampling visits) for Miscanthus or SRC willow fields (each 0.4 km per visit, and between two to five visits). Following log_{10} transformation, after adding an
offset of one to allow for zeros, the mean logged count and variance was computed over all sites for each crop. For each group the difference between the Miscanthus or SRC willow and FSE mean logged counts was then computed along with a 95% confidence interval. The mean and confidence limits were then back-transformed to the ratio scale.

The abundance of total butterflies was significantly greater in field margins surrounding both Miscanthus and SRC willow than in the headlands of arable crops. There were 60% and 132% more butterflies in headlands of Miscanthus and SRC willow, respectively, than in arable headlands. The abundance of families of butterflies varied between headlands of biomass crops and the arable break crops, where the abundance of the Pieridae in Miscanthus and SRC willow field margins was significantly lower than in arable field margins at 56% and 64%, respectively. Except for Lycaenidae in Miscanthus headlands, all other families of butterfly were significantly more abundant in headlands of biomass crops than in those surrounding arable crops. The Satyrinae showed the largest differences of 370% and 620% in Miscanthus and SRC willow respectively, (Figures 5 and 6) (Haughton et al. 2009).

**Figure 5** Mean proportion (R) of families of butterfly in field margins around Miscanthus crops to arable crops. Dashed line is line of unity. Error bars around mean are 95% confidence limits, back-transformed to the ratio scale (hence asymmetry) (adapted from Haughton et al. 2009).

**Figure 6** Mean proportion (R) of families of butterfly in field margins around SRC willow crops to arable crops. Dashed line is line of unity. Error bars around mean are 95% confidence limits, back-transformed to the ratio scale (hence asymmetry) (adapted from Haughton et al. 2009).
While we already know that commercial SRC can be good for certain groups of farmland and scrub type birds on UK farmland (Sage et al, 2006), relatively little work has been undertaken in Miscanthus. Semere & Slater (2005) and Bellamy (In Press) did find a variety of farmland birds using Miscanthus plots. However the fields available to these studies tended to be agronomically poor (excessively patchy cropping and weedy, as documented by the authors) and hence commercially unrepresentative, which we think heavily influenced bird use. In the Defra-funded complementary project on biodiversity some simple bird monitoring work was therefore included at a subsample of 16 recent commercial Miscanthus sites in winter and summer to address this imbalance. Comparisons were made with adjacent fields of grass or cereals, and, in summer, only with a handful of SRC fields that had been cut the previous winter (because meaningful comparisons with past data were not possible due to substantial methodological differences).

Here we present summary data for birds in summer. In May and June Miscanthus crop height was low enough to allow birds to be surveyed by systematically walking transects through the crop (as in the controls). In July, the height and density of the Miscanthus (>2 m) meant a novel technique was required involving two surveyors, one watching from a high vantage point (usually a deer seat) whilst the other walked through the crop flushing birds. We found that encounters with territorial males in Miscanthus in May and June were very low compared with the cut SRC, and in June, slightly lower even than the (much larger) cereal control fields (Figure 7). In July, encounters with post-breeding individuals, primarily blackbirds and reed buntings, in Miscanthus increased overall densities but again were much lower than in the recently cut SRC.
[b]Hydrology

As Miscanthus and SRC willow are deeper rooting than other arable crops and have a longer growing period, land conversion to energy cropping may have implications for water resources. Howes et al. (2002) concluded that the effects of energy crop production on water quality were likely to be beneficial due to the reduced requirement for nitrogen fertiliser and pesticide inputs. However, there is serious concern about amounts of water needed by energy crops and the possible implications for stream flow and groundwater recharge. With the introduction of the Water Framework Directive (WFD) this concern relates not only to the direct impacts on resource availability, but also to the implications of lower flows for the ecology of water courses. There have been two major studies into the potential hydrological impacts of energy crops in the UK, both carried out by CEH. In the most recent, Finch et al (2004) concluded that there was no simple answer since the balance of impacts depended on the type of energy crop, the land cover replaced, soil characteristics and climatic variables. Moreover, these studies were based on limited numbers of measurements, particularly for Miscanthus, so there were significant uncertainties in the predictions that could be generated for different rainfall scenarios.

In Relu-Biomass, the significant body of previous work on the water use of SRC willow was used to provide parameter values and data for the calibration of a numerical model of the land surface water and energy balance, based on Finch (2001). In addition, two full years of measurements of the land surface fluxes of water and energy were carried out to test the
outputs of the model. The collected dataset was used to quantify the uncertainties in the modelled output. Previous work showed that the differences in water use of the different willow varieties studied were less than the uncertainties in the measurements and model predictions so predictions for a ‘typical’ willow SRC type can be made.

Although there is only one variety of Miscanthus currently grown in the UK, there is comparatively little information on its water use. Recently published studies suggest that the water efficiency is atypical of plants that use the C₄ photosynthetic pathway. In particular, it appears that, in southern England, it is able to maintain high quantum yield assimilations of CO₂ in the early growing season despite low temperatures, i.e. < 12°C. This has major implications for predictions of both the growth and the annual water use which are likely to be higher than estimated by Finch et al. (2004). In Relu-Biomass measurements have been made at two sites in order to provide parameter values for and to test the numerical model.

A range of automatically logged and manually operated instruments were used at sites of both crops to measure: (i) net radiation, soil heat, latent heat, sensible heat fluxes (the latter two using eddy covariance); (ii) soil water content using Profile Probes and a neutron probe; (iii) soil water potentials using pressure transducers; and (iv) forcing variables using an Automatic Weather Station (AWS). Additional measurements were made at the Miscanthus site: (i) stomatal conductance using an Infra Red Gas Analyser (IRGA); (ii) Leaf Area Index (LAI) using a sunfleck ceptometer, and canopy height; and (iii) throughfall using a system of troughs and tipping bucket raingauges.

Although the analysis is not fully complete, the results so far appear to confirm the hypothesis that the water use of Miscanthus is higher than that given by Finch et al (2004), because of a
longer growing period. As a consequence of the deeper rooting depth of *Miscanthus*, compared to the majority of other agricultural crops, water use (and by implication yield) are only likely to be limited by the availability of soil water during exceptionally dry summers, such as occurred in 2003. About 55% of the total annual water use is made up by transpiration of the crop, the remainder being due to evaporation from the soil and interception (rainfall caught on the leaves and evaporating directly back into the atmosphere). Although leaf fall is mainly complete by the end of the year, there is a significant water loss due to interception in the autumn (Figure 8). As a result, around two thirds of the water use occurs in the second half of the year, very different to the situation with cereals such as winter wheat.

**Figure 8** Simulated cumulative total water use of *Miscanthus* and its components: crop transpiration, soil evaporation and crop interception loss.

[b]Rural economics

The uptake of energy crops by UK farmers will depend on a range of economic factors. Whilst there is already considerable experience of the issues involved in policy-driven attempts to substantially modify traditional and conventional farming systems, for example through the introduction of various agri-environment schemes, the adoption of energy crops, such as SRC and *Miscanthus*, will require major changes in farm planning horizons (Turner, 1999). Coupled with this, the requirement for incentive payments to facilitate uptake by farmers needs to be balanced with wider issues including a clear identification of the rationale for Government intervention and an assessment in terms of value-for-money criteria. Once an energy crop supply-chain infrastructure is established, returns equivalent to some arable crops could be achieved by UK farmers. However, the initial investment required to establish the crop and secure a market can be prohibitive, introducing risk. In addition, the low input
nature of the crops may have implications for the wider rural economy as large scale changes of land use to energy crops could reduce demand for seeds, fertiliser, pesticides, machinery and labour, so negatively affecting the agricultural supply trade. There has been no previous attempt to quantify this possible effect.

In Relu-Biomass the basic farm-level economics of energy crop production was studied by focussing on the following aspects. First, an examination was undertaken of the establishment of definitive baseline costs of energy crop production, expressed on an annual equivalent value basis, inclusive of short run and long run cost profiles. Second, a review of the impacts on farm business organisation and management was carried out, including its implications for cash flows (both short and long term), capital investment cycles (e.g. requirements for specialised machinery), and farm structures and systems (including the potential use of agricultural contractors). Third, an investigation was undertaken to identify the effects on farm resource utilization, including seasonal/cyclical implications in the demand for labour. The medium term implications of the recent ‘decoupling’ reform of farm support under the Common Agricultural Policy on farmers’ attitudes to long term crops such as Miscanthus and SRC were then examined. Finally an attempt was made to gain insight into the likely dynamics of energy crop uptake through estimation of the energy supply curve, under different farm system scenarios, at different prices and under competing alternative cropping assumptions.

The economic appraisal was based on modelling of the impact on, and scope for integration with, a number of alternative farming systems, assuming the replacing of both arable crops and grassland. The research drew on published economic data and involved focussed surveys of farmers and farm managers. In addition, aspects of farmers’ decision-making was
addressed through identifying those issues of significance in investing for long-term production patterns.

Whilst the full analyses of the study results have not yet been completed, it is clear that plantings of these biomass crops has taken place within a very wide range of farming systems and farmer decision-making has been driven by diverse factors. Similarly, the survey has uncovered a considerable range in terms of planted areas per holding, both in absolute terms (as land area) but also as a proportion of the farmed area. So one tentative conclusion is that, on the evidence to date, the adoption of biomass as an agricultural enterprise is such that the traditional English patchwork of cropping has so far not been seriously challenged, simply modified by the addition of a novel crop. For largely historical reasons, the majority of Miscanthus has been grown in the south west and, more recently, the Midlands, while most SRC has been in the north east, but this pattern is changing quite rapidly. In terms of production economics it is evident that, although the commercial attractiveness of biomass crops looked highly questionable in the context of 2007 cereal prices, the situation in the autumn of 2008 looks very different.

The contrasting experiences provided by the volatile returns from cereal growing over the past two seasons, not the only alternative to biomass by any means but nevertheless a benchmark comparison for many, underline both the weakness and strength of biomass and point to its likely future role on many farms. Its low returns mean that it is unlikely to be the dominant enterprise on most farms, except in special circumstances such as where the farmer is looking for a reduced commitment of time and effort; but the predictability of those returns may look very attractive as part of a risk management strategy in an era of greater market volatility. In terms of the wider rural economy, the conclusions are already clear: biomass
production provides less employment and requires a smaller supply infra-structure than conventional food crops. The implications of this depend largely on the scale of plantings in the years to come.

[a] Integrative approaches in Relu-Biomass

[b] GIS-based constraints mapping

GIS techniques have been used to perform a variety of data assembly and integrative roles during the research in Relu-Biomass. A constraint mapping exercise (see Lovett et al, 2009) has been carried out based on a review of previous policy documents and studies (e.g. Capener et al, 2004; Defra, 2006; Centre for Sustainable Energy, 2007). A series of data layers were compiled at a 100m resolution for the whole of England with the following 11 factors incorporated into overlays:

**Unsuitable soil types
**Biodiversity Action Plan priority and semi-natural habitats
**Existing woodland
**Slope steepness
**Urban areas
**Major rivers
**Lakes
**Designated Areas (e.g. SSSIs etc)
**Cultural heritage
**Landscape sensitivity
**Improved Grassland
A total area for England was calculated in the GIS as 13,039,461 ha. The first nine factors listed above were regarded as absolute constraints and excluding the areas covered by any of these reduced the available land to 7,770,628 ha (59.6% of England). Two additional factors; environmentally sensitive landscapes and improved grassland, are not absolute constraints to the planting of perennial energy crops such as *Miscanthus*, but represent types of areas where there would be reasons for avoiding extensive planting. Including these constraints as well reduced the available land by over 3 million ha to 4,719,756 ha (36.2% of England). When this was then further restricted to Grade 3 or 4 land (intermediate to poor categories where ECS data show that energy crops are currently being planted), the resulting distribution of potentially suitable land was as shown in Figure 9 and totalled 3,120,173 ha (23.9% of England).

**Figure 9** *Land outside the 11 planting constraints and classed as Grades 3 or 4.*

This analysis was combined with a yield mapping exercise through collaboration with another RCUK funded project, TSEC-Biosys (www.tsec-biosys.ac.uk). An empirical yield model (Richter et al, 2008) was combined with the GIS data to produce yield estimates for the land highlighted in Figure 8 and the results were compared with agricultural census data on the distributions of currently grown food crops. This analysis indicated that areas with the highest biomass yields do co-locate with important food producing areas. Nevertheless, investigation of a scenario involving energy crop planting on 350,000 ha (a target in the UK Biomass Strategy for 2020, DTI et al, 2007) suggested that this could be achieved without requiring higher grade land and so would not necessarily greatly impact on UK food security. GIS-based yield and constraint mapping can thus help identify important issues in bioenergy
generation potentials and land-use trade-offs at regional or finer spatial scales that would be missed in analyses at the national level (Lovett et al, 2009).

GIS analyses were also used to help identify appropriate locations for the public questionnaire surveys and focus groups as described in Section 3 (a) above. In addition, detailed GIS maps for smaller areas (based on Ordnance Survey MasterMap) provided the framework for the landscape visualisations described in Section 3 (a). All the suitability maps will be updated as additional data become available from other disciplines in the project and integration of the research on hydrology, biodiversity and economics is currently being investigated.

[b]Sustainability Appraisal (SA) framework

SA is an objectives-driven approach, which relies on the derivation of aspirational sustainability objectives, against which different plan performances can be compared. In the SA approach measurable empirical objectives are identified by engaging stakeholders with relevant scientists. Targets and indicators of these empirical objectives are then used to assess the performance of alternative plans. Essentially, SA can be seen as an analytic-deliberative process which fuses quantitative, expert-derived data with stakeholder concerns and values (see Petts, 2003; Wiklund, 2005; Chilvers, 2007). SA has been criticised as being a process which facilitates trade offs whereby environmental impacts can be offset by economic benefits (Morrison-Saunders and Fischer 2006; Gibson, 2006) (this suggests, for example, that planting may be seen as appropriate in environmentally designated areas, or Areas of Outstanding Natural Beauty). In Relu-Biomass, the potential for such trade offs has been avoided through the combination of SA with constraints mapping, whereby the SA is applied only to the land area not screened out under any of the other constraints.
At the onset of the Relu-Biomass project, a scoping exercise involving a literature review and consultation was used to identify the impacts that needed to be assessed. This involved discussion and collaboration between all the partners from the different disciplines in the project. Initial objectives, targets and indicators were identified for each discipline and existing work reviewed to see if suitable measures existed or if new ones need to be derived.

It was clear that a separate SA framework was required for each study region to take into account existing regional plans and programmes, tensions with other policies and analysis of existing baseline sustainability conditions (Office of the Deputy Prime Minister, 2005). Stakeholder lists were drawn up for each region, including: farmers; energy companies; central, regional and local government; NGOs (e.g. National Farmers’ Union); Natural England; Environment Agency; English Heritage; Forestry Commission; SRC willow and Miscanthus businesses; and academics. One-day stakeholder meetings were held to brainstorm (Donnelly et al, 2006) and legitimise (see Owens et al, 2004) appropriate sustainability objectives which, through an iterative process of development by scientists and reviews by stakeholders, were then accepted as the basis for the SA framework. Table 1 indicates the objectives selected and demonstrates the broad scope of stakeholder concerns which need to be taken into account in decision-making related to planting decisions.

A similar process was used to generate indicators which were evaluated against criteria for examining the suitability of indicators for SA (see Donnelly et al, 2007). The criteria demand that indicators should be policy relevant, cover a range of environmental receptors, be
Table 1  Stakeholder derived sustainability objectives for the two regions.

<table>
<thead>
<tr>
<th>East Midlands Objectives</th>
<th>South West Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimise transport movements</td>
<td>Minimise additional vehicle movements</td>
</tr>
<tr>
<td>Enhance rural quality of life</td>
<td>Enhance rural quality of life</td>
</tr>
<tr>
<td>Increase water availability</td>
<td>Maintain water availability</td>
</tr>
<tr>
<td>Improve public enjoyment of the countryside</td>
<td>Improve public connection with the countryside</td>
</tr>
<tr>
<td>Safeguard the historic environment</td>
<td>Safeguard the historic environment</td>
</tr>
<tr>
<td>Reduce energy costs to the consumer</td>
<td>Reduce energy costs</td>
</tr>
<tr>
<td>Increase amount of energy produced locally</td>
<td>Increase amount of energy produced and used locally</td>
</tr>
<tr>
<td>Increase the viability of local economies</td>
<td>Increase the viability of local economies</td>
</tr>
<tr>
<td>Enhance tourism potential</td>
<td>Maintain tourism resource</td>
</tr>
<tr>
<td>Enhance viability of farming</td>
<td>Enhance viability of farming</td>
</tr>
<tr>
<td>Maximise waste management opportunities</td>
<td>Maximise waste management opportunities</td>
</tr>
<tr>
<td>Enhance employment</td>
<td>Enhance rural employment</td>
</tr>
<tr>
<td>Enhance local landscape character</td>
<td>Enhance local landscape character</td>
</tr>
<tr>
<td>Improve water quality</td>
<td>Improve water quality</td>
</tr>
<tr>
<td>Protect soil resources</td>
<td>Protect and improve soil resources</td>
</tr>
<tr>
<td>Improve air quality</td>
<td>Improve air quality</td>
</tr>
<tr>
<td>Protect and enhance biodiversity</td>
<td>Protect and enhance biodiversity</td>
</tr>
<tr>
<td>Reduce greenhouse gas emissions</td>
<td>Reduce greenhouse gas emissions</td>
</tr>
<tr>
<td>Maintain food security</td>
<td></td>
</tr>
</tbody>
</table>

relevant to the plan in question, show trends; be easily understandable to the public and decision makers, be well founded technically and scientifically, prioritise key issues, provide early warning, and, be adaptable to reflect differing circumstances.

In developing the SA framework it became clear that some of the existing indicators are not suitable and that better indicators could be derived from the results of the research activities in the project. In particular, a specific challenge in relation to biomass crops is to identify more appropriate measures to examine the biodiversity implications of changing a proportion of
land from conventional arable crops to biomass crops. The SA framework stakeholder discussions revealed that, while biodiversity was of concern, current indicators of biodiversity are not appropriate. The initial results of Relu-Biomass biodiversity studies have shown that butterflies are sensitive to the change to biomass cropping (Haughton et al. 2009). Other research and researchers have also shown that butterflies respond quickly and consistently to various changes in environmental factors. We have proposed, therefore, that butterflies might prove more appropriate and reliable than other more commonly used indicators of environmental change, such as birds (Haughton et al, 2009). As more of the results from the biodiversity studies in the project become known, as well as the hydrology and economic research, it is anticipated that further indicators will be identified that are more appropriate for biomass crops compared to the existing ones. Ultimately, use of better indicators will enhance the analytic component of SA which could have far reaching implications for the level of understanding of the social, economic and environmental consequences of future decision-making in many sectors.

In the latter phases of Relu-Biomass, the SA framework is being used to assess the impact of different planting scenarios. These include differences in: total land cover taken up by biomass crops; biomass end use; crop management in terms of field distribution/pattern and crop management in terms of headland size.

For each scenario the wider stakeholder community will be consulted and the scenarios will be compared and modified through an iterative process to identify the most appropriate one for each type and region relative to sustainability objectives. Results will be written in the SA, report which will also examine the practicalities of undertaking SAs for energy crops and the key quality assurance issues that need to be addressed. Our findings will be discussed with
stakeholders to produce authoritative science-based recommendations for planners and other professionals involved in conducting environmental assessments of energy crop planting schemes.

[a]Concluding remarks

The potential for energy crops to contribute to the future energy supplies through providing a source of renewable carbon for heat and power and liquid transport fuels has been recognised by governments throughout the world. However, policy changes, rising concerns over the economic viability of energy cropping and increasing awareness of possible impacts on food security, water and other environmental issues, have checked the growth of the bioenergy and biofuel industries. Scientifically-based approaches which enable policy- and decision-makers to examine the possible impacts of different scenarios of energy crop plantings are urgently needed. For this to be satisfied, a robust evidence base and holistic approaches which enable integration across the different social, economic and environmental disciplines are also required. The UK interdisciplinary Relu-Biomass project has focussed on filling in knowledge gaps though targeted research on the impacts of SRC willow and Miscanthus on visual appearance, social acceptability, biodiversity, hydrology and rural economics and has developed two approaches to provide integration and decision-making tools: GIS-based constraints mapping and Sustainability Appraisal. Continual engagement with stakeholders has been an essential component of the project and in future, the expectation is that the tools will be utilised in planning expansion of energy crop plantings in the UK in ways which maximise positive impacts and minimise negative ones.
[a]Acknowledgements

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[a]References


Department of Trade and Industry (DTI), Department for Transport (DfT) and Department for Environment, Food and Rural Affairs (Defra). (2007) UK Biomass Strategy


