Socio-economic constraints on renewable energy in the UK: Understanding barriers to the development of perennial energy crops and onshore windpower

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Declaration

I have read and understood the University of Edinburgh guidelines on Plagiarism and declare that this written thesis is all my own work except where I indicate otherwise by proper use of quotes and references.

[redacted]

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Acknowledgements

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I would like to dedicate this work to Murray, who is now three years old, and Megan who has just turned one. I hope that by the time that they are old enough to read it, we will have begun to more effectively tackle many of the serious problems that this world faces. I hope that in a small way this work has shed light on how we can better deal with some of these important challenges.

Abstract

In seeking both to tackle climate change and ensure that the UK has a secure supply of affordable energy, the UK Government is proposing a significant expansion in the generation of energy from renewable sources. Under the Renewable Energy Directive, the UK is committed to providing renewable sources for 15% of its total energy use by 2020. While there is considerable theoretical potential, a number of socio-economic constraints threaten the achievement of this target. This research develops a more quantitative understanding of such constraints for two renewable energy sources with significant potential; perennial energy crops, and onshore wind power. For perennial energy crops such as Short Rotation Coppice (SRC) Willow, and Miscanthus, a major constraint is the extent to which UK farmers will commit land to the production of these relatively novel crops. For onshore wind power, a key constraint is that of public perception, related primarily to the visual impact on landscapes. The research uses a number of approaches, drawing on social-psychology techniques, mathematical programming, and cost-benefit analysis, to develop a better understanding of the nature and extent of key barriers. As a result, a number of policy relevant findings lead to the identification of cost-effective ways in which barriers to development can be addressed.

Keywords: Renewable energy, socio-economic constraints

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Chapter 1

1.0 Thesis Structure

The first chapter of this thesis introduces the area of research, and briefly outlines the policy context, the specific research questions, and the methods and approaches that are used and reported on in the four chapters that follow.

These four main chapters of the thesis are based on papers that have either been published in an academic journal (Chapters 2, 3 and 5) or in conference proceedings (Chapter 4). Accordingly, as is the case with such journal papers, relatively little space was available for methodological and critical review. Furthermore, these chapters that draw on published articles have not simply been reprinted, but have been edited to make them appropriate for the thesis. Therefore, the approaches and methods used in the reported studies are *briefly* reviewed at appropriate places in the individual chapters, with a more in depth critical review taking place in Chapter 6.

The four published papers each have a number of authors, and the division of labour and responsibilities are as follows:

Chapter 2 is based on Sherrington, C., Bartley, J. and Moran, D., 2008. Farm-level constraints on the domestic supply of energy crops in the UK, Energy Policy 36, 2504 - 2512. Justin Bartley of the Institute for European Environmental Policy was responsible for arranging venues for the three focus groups, recruiting farmers, and writing up his own notes from the meetings which were then cross-checked by the lead author, to ensure that his own reporting of the findings had covered all the relevant points. The lead author prepared the questions for the focus groups, and wrote up notes based on the farmers' statements, which were also recorded on an audio tape. To enable the lead author and Justin Bartley to concentrate on noting responses, the focus groups were facilitated by an independent consultant. The lead author attended the first focus group, and wrote up his notes from that group having listened again via the recording. The lead author did not attend the next two focus groups, but listened through twice to the recordings, and checked his notes against those of Justin Bartley. The lead author wrote the paper, including the introduction to the relevant agricultural and energy policies, consideration of levels of energy crop uptake to date and the key recommendations. Dominic Moran reviewed the final paper before submission. The published paper is reproduced in full as Appendix A.2.0

Chapter 3 is based on Sherrington, C. and Moran, D., 2008. Farmer attitudes and intentions towards the adoption of perennial energy crops in the UK: An application of the Theory of Planned Behaviour, Proceedings of the 16th European Biomass Conference, Valencia, Spain, 5th June 2008. The lead author prepared and trialled the questionnaires, undertook all the statistical analysis and wrote the paper. Dominic Moran reviewed the paper before submission. This conference paper is reproduced in full as Appendix A.3.0

Chapter 4 is based on Sherrington, C. & Moran, D., (2010) Modelling farmer uptake of perennial energy crops in the UK, Energy Policy 38, 3567 - 3578. The lead author undertook all of the modelling and wrote the paper, which was reviewed by Dominic Moran before submission. The published paper is reproduced in full as Appendix A.4.0

Chapter 5 is based on Moran, D. & Sherrington, C., 2007. An economic assessment of windfarm power generation in Scotland including externalities, Energy Policy 35, 2811-2825. While C. Sherrington was in fact the lead author, undertaking all of the modelling and preparation of the paper, due to a misunderstanding during submission, the details were incorrectly recorded. The paper was reviewed by Dominic Moran before submission. The published paper is reproduced in full as Appendix A.5.0

2.0 Introduction

In seeking both to tackle climate change and ensure that the UK has a secure supply of affordable energy, the UK Government is proposing a significant expansion in the generation of energy from renewable sources (DECC, 2009a). Measures set out in the 2007 Energy White Paper were intended to increase the proportion of overall energy needs - that is a combination of electricity, heat and transport fuel - met by renewable sources from their current level of 1.5% to 5% by 2020 (DTI, 2007). Since then the UK has committed to the more ambitious EU-wide target within the Renewable Energy Directive to source 20% of the EU's total energy use from renewable sources by 2020 (European Parliament and Council of the European Union, 2009). The UK's contribution towards this target is to provide renewable sources for 15% of its total energy use by 2020 (European Parliament and Council of the European Union, 2009). This would represent a ten-fold increase in levels of renewable generation over the next decade.

The UK Government's Renewable Energy Strategy, which outlines how this level of generation could be achieved, indicates that with the largest wind resource in Europe wind power could provide two-thirds of the UK's renewable electricity by 2020, while around 30% of the UK's overall renewable energy target, for heat, transport fuel and electricity, could come from biomass (DECC, 2009a).

There are a number of barriers that threaten the attainment of these targets. For biomass energy, the potential for imports notwithstanding, a key consideration is whether UK farmers will supply sufficient feedstock. This thesis therefore concentrates on barriers to the adoption by farmers of perennial energy crops such as short rotation coppice (SRC) willow, and miscanthus. For wind power, opposition to the visual impact of windfarms, and the way in which the planning system deals with this issue has long been seen as a key barrier to development, and this thesis therefore considers the way in which the attributes of onshore wind proposals are evaluated.

The central contention of this thesis is that a clear understanding of the nature of these barriers is necessary not only to enable the targets to be achieved, but to ensure that they can be achieved in an efficient manner.

This introductory chapter is structured as follows. The potential UK biomass resource is briefly outlined below, highlighting the important role of perennial energy crops in the Government's ambitions for enhancing the domestic supply of biomass. Having illustrated this potential, a number of salient barriers to the adoption of perennial energy crops, as identified in the course of the research for this thesis, are highlighted. The three papers that investigate and develop an understanding of farm level barriers to adoption are then introduced, with a description of the focus of each, and an explanation of the way in which each piece of research develops the key arguments.

The potential for further development of wind power in the UK is then introduced, alongside an initial consideration of the role of the planning system in assessing which projects should proceed, and the extent to which planning can act as a barrier to the achievement of national targets. The fourth paper in the thesis, applying an alternative approach to the evaluation of an onshore windfarm proposal in Scotland, is then introduced.

There are some illustrative contrasts between two main areas of focus, as well as a number of common themes that became evident through the research. These common themes are discussed prior to a more in-depth introduction to the research approach to each of the papers.

2.1 Barriers to the adoption of perennial energy crops

The term 'biomass' covers a range of renewable fuels derived from organic matter, of which there are a number of possible sources in the UK. These include landfill gas, sewage gas, forestry, wood waste, conventional agricultural crops such as wheat and oilseed rape, straw, perennial energy crops, and agricultural waste (RCEP, 2004; Defra, 2007). To increase available biomass, Defra (2007) favours obtaining an additional 1 million dry tonnes of wood per annum from woodland and wood waste, more use of manures and slurries, and a substantial growth in the uptake of perennial energy crops such as short rotation coppice (SRC) willow and miscanthus. Of these sources, it is the anticipated change in levels of perennial energy crops that is most dramatic, from under 16,000 hectares (ha) at present to 350,000 ha by 2020. This represents approximately a 20-fold increase, and would occupy roughly 6.5% of UK arable and set-aside land (Defra, 2007).

Despite the implementation of a number of Government backed schemes to support the adoption of perennial energy crops by UK farmers over the past decade, the area of land allocated to such crops has fallen far short of stated scheme objectives (Sherrington et al., 2008; RELU, 2009). Looking ahead, the research undertaken for this thesis suggests that UK farmers are not actually likely to supply perennial energy crops to the extent envisaged by the UK Government, unless a number of barriers to their adoption are overcome. Furthermore, while the Government has acknowledged that uptake to date has been lower than anticipated, their preferred method of stimulating supply, even if successful, is shown, through this research, to be a more expensive approach than could be achieved through directly tackling these barriers. The three papers in this thesis that investigate farmer attitudes and intentions towards the adoption of perennial energy crops, include a number of important recommendations for policy makers.

The central argument about the nature of the barriers to adoption is progressively developed through the three papers, with each building upon, and re-inforcing, the core findings and policy recommendations.

The first, (Sherrington et al., 2008) forms the basis for the two subsequent papers by reporting the findings of three focus groups. These involved a mixture of farmers who were already growing perennial energy crops, and those who were considering, or had chosen not to grow these crops. Each focus group was undertaken in an area where markets for perennial energy crops existed, and where supply contracts were available. The research identified a number of important barriers to adoption for both miscanthus and SRC willow, with the findings reported, and the paper referenced, in a supporting document to the Gallagher Review (Woods and Black, 2008).

The second paper, (Sherrington & Moran, 2008) took barriers (and drivers) identified by the focus groups, and tested the relative importance of each through application of a social-psychology technique, the Theory of Planned Behaviour (Ajzen, 1991). The use of a postal survey enabled coverage of a large enough sample of farmers to ensure that the results were of statistical significance. Farmers were asked about their behavioural intentions, attitudes, social norms and their perception of behavioural control towards adoption of perennial energy crops. The results of this research were presented to the TSEC-Biosys consortium, prior to their publication at the 2008 European Biomass Conference, in Valencia, Spain. The research identified that UK farmers were not likely to grow perennial energy crops due to the existence of a number of financial (and arguably non-financial) barriers. From these findings a number of significant recommendations for policy makers were developed.

The third paper, (Sherrington & Moran, 2010) abstracts from the barriers identified in the first two papers, and investigates the level of adoption of perennial energy crops that would theoretically be achieved at different levels of gross margin (revenue minus variable costs). The linear programming modelling approach treats perennial energy crops as 'another activity' in which the farmer might engage. The results suggest that taking account of existing support schemes and contracts, adoption of perennial energy crops should be significantly more widespread than at present. While theoretically profitable, the disparity between model and reality acts to confirm the existence and significance of the barriers identified by the previous papers. Again, a number of recommendations for policy makers arise from this paper.

2.2 Barriers to the development of wind power in the UK

While farmers may not have shown great enthusiasm towards the adoption of perennial energy crops, by stark contrast, what has by some been termed a 'wind rush' is currently taking place in the UK (Country Guardian, 2009). There exists, due to the financial support available through the Renewables Obligation, a considerable appetite on the part of developers to construct and operate windfarms.

The Government's Renewable Energy Strategy suggests that meeting the 2020 target would require an installed capacity of approximately 14GW of onshore wind (DECC, 2009a). Onshore there is currently 3.2GW installed, 0.8GW under construction, and 3.4GW with planning approval – totalling 7.4GW, which is just over half way to meeting the target. There is another 7.4GW awaiting planning permission, which, if approved would be sufficient to meet the 14GW target (BWEA, 2009). Subject to planning permission, the Government expects that a large proportion of onshore wind development will take place in Scotland (BERR, 2008).

A significant potential constraint on the attainment of these targets is therefore, as alluded to above, whether sufficient schemes will actually be granted planning permission. The issue of negative public perception of windfarms, primarily relating to the expected visual impact, has caused many applications to be rejected to date. Figures released in October 2009 indicate that in the preceding ten months only 25% of windfarm planning applications submitted to local planning authorities (for sites of less than 50MW capacity) were approved, with approvals on subsequent appeal to the Planning Inspectorate higher at 62% (BWEA, 2009).

It is the role of planning authorities to determine, albeit not within the framework of a formal cost-benefit analysis, the 'costs', especially for negative impacts on landscape, and the benefits, such as the predicted carbon savings, that would arise from each proposed windfarm. However, without a formal cost-benefit analysis, there is no clear metric for authorities to assess whether a particular project delivers an overall benefit to society. The process, which is largely descriptive, fails effectively to quantify the extent of the likely visual disamenity, and as such makes for a largely subjective decision on the part of planning authorities as to whether or not an individual proposal should proceed. It is even more difficult, using this approach, to compare competing projects in different locations, and thus engender a level of consistency in decision making.

The result of this, beyond concern among groups such as RenewableUK [1] that targets simply won't be met, is uncertainty over whether the most efficient locations, in terms of the range of associated social costs and benefits, are being granted permission. In societal terms, it is desirable to achieve the targets for installed capacity in a cost-effective manner, which is something that cannot be ensured under the present system.

The fourth paper in this thesis demonstrates an alternative approach, applying non-market valuation techniques to place a monetary value on the visual disamenity arising from a proposed windfarm. Using this value alongside the monetised benefits from avoided carbon emissions, and the financial costs and benefits associated with the project, means that proposals can be compared in a framework that allows for transparent and consistent assessment. The approach is applied to a proposed (and since consented) large windfarm in South Lanarkshire, Scotland. Wider application of such a technique is argued to have the potential to enable selection of the most efficient projects that should deliver the greatest possible carbon saving from UK windfarms at least social cost.

2.3 Common Themes

The core argument of this thesis, is that a better understanding is needed of these barriers to the development of renewable energy in the UK, in order that targets can be achieved, and achieved in an efficient manner. This theme runs through all four papers, and in juxtaposing perennial energy crops against wind power, illustrates the issues that affect renewable energy technologies (and associated inputs) at different stages in their development.

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[1] The organisation previously known as the British Wind Energy Association

For perennial energy crops, which for farmers represent a novel crop with associated uncertainties, the investigation is essentially focused on private costs and benefits, from the farmer's point of view. The research is trying to understand how the theoretical benefits, in terms of financial return, can most cost-effectively be realised, and how the real and perceived costs can best be tackled.

For wind, from the private perspective, the benefits already outweigh the costs as can be seen from the large number of planning applications that have been submitted by developers. The technology is proven and well understood, and the assessment is therefore on the wider societal costs and benefits. However, should perennial energy crops be adopted on such a scale as to lead to public concern over visual despoliation of the countryside, the analytical approach as applied to the Scottish windfarm could equally be used to assess the social costs and benefits associated with large scale planting of miscanthus or SRC willow.

The remainder of this introduction is structured as follows. Firstly, the technical potential of perennial energy crops in the UK is outlined, along with a number of potential constraints that have been identified in the literature. The research approach is then introduced in more detail, and the progression through the three related papers is explained. Subsequently, the theoretical potential and possible constraints on the development of wind power in the UK are discussed, leading to an overview of the techniques applied in the fourth research paper.

3.0 Perennial Energy Crops: Background and Research Approach

3.1 Technical potential of perennial energy crops in the UK

The technical potential of energy crops is estimated to be 17.2 TWh [2] (1.48 Mtoe) [3], while current availability is 0.07-0.09 Mtoe (Defra, 2007). To reach the technical potential of perennial energy crops by 2020 (Defra, 2007), would require 350,000 hectares (ha) of land, which is roughly 6.5% of UK arable and set-aside land, assuming an average annual yield of 9odt/ha [4] (Defra, 2007). The Renewables Innovation Review (DTI, 2003a) suggests this is a realistic area once a number of constraints, including competition from other markets, are taken into account.

A recently developed range of energy crop scenarios used to inform the Renewable Energy Strategy suggests that by 2030, using both arable and pasture land, the potential could be up to 2.2 million hectares (E4Tech, 2009).

The key feature of all these estimates is the assumptions about farmer behaviour. They take for granted that sufficient farmers will choose to grow perennial crops up to the level of the constraints that they identify. However, this assumption does not seem to be supported by experience to date.

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[2] Terrawatt hours (One terrawatt is a trillion, or 10^{12} watts)

[3] Million tonnes of oil equivalent

[4] Oven dried tonnes

3.2 Current uptake of perennial energy crops in the UK

Defra's Energy Crops Scheme, which provides establishment grants for SRC willow and miscanthus, was intended to support the planting, by 2006, of 16,700ha of SRC and 5000ha of miscanthus in England (ADAS, 2003). When the scheme closed to applications, in July 2006, only 1,180 hectares of SRC and 3,356 ha of miscanthus had been planted, however, increased interest in the payments, saw applications for planting in 2007 set to take the area of miscanthus to 12,627ha, and SRC to 2,600ha in England (Defra, 2006).

In Scotland, the area planted or approved for planting up until the end of 2006 was 300ha, with applications for planting in 2007 and 2008 amounting to around 600ha (SAC, 2007a). In Northern Ireland, 810ha of SRC have been planted or approved for planting (DARDNI, 2007), while in Wales there is known to be 40ha of SRC and 72ha of miscanthus (Welsh Assembly Government, 2007).

The latest published figure for the total area of perennial energy crops in the UK is 15,546ha for SRC willow and miscanthus combined (Defra, 2007), however it is believed that the planted area is now around 17,000ha (RELU, 2009).

3.3 Potential barriers to adoption

There is a growing literature on perennial energy crops and the development of biomass energy in the UK, Europe and beyond. While there has been much focus on techno-economic aspects and theoretical supply chain potential, broad stakeholder opinion, and wider public policy implications, less is known about how individual farmers will choose to respond to the opportunities presented by these crops. Strawson (2005), writing from the perspective of a farmer with land already committed to SRC Willow, and at a time when returns from alternative activities were much lower than at present, offers a relatively upbeat assessment of the potential attractiveness of the crop. However, he does identify that some farmers have concerns about the long-term commitment of energy end-users, and the ease of returning fields to arable production, while the collapse of the ARBRE (Arable Biomass Renewable Energy) project at Eggborough, North Yorkshire, in the late 1990s, serves as a focus for farmer unease (Strawson, 2005).

The suggestion of potential barriers to adoption identified by Strawson (2005), combined with the low uptake indicates that farmers' attitudes towards perennial energy crops need to be better understood. In addition to issues of cultivation and the commitment of energy end-users, perennial energy crops can be considered as a novel enterprise for UK farmers due to their position at the interface between agricultural and energy policy. This brings a greater number of uncertainties than exist with conventional agricultural activities. Several authors have argued that uncertainty is a key barrier to the successful uptake of emerging renewable technologies such as bioenergy, principally because it hinders the fulfilment of entrepreneurial activities. In order for entrepreneurs to act, motivation needs to outweigh perceived uncertainty. Therefore, identifying dominant sources of uncertainty can deliver valuable insights for policy makers (Meijer et al., 2007).

In addition, many systems such as energy and agriculture are characterised by lock in and resistance to change through technological, institutional and social path dependency, resulting in a variety of barriers for new innovations such as energy crops and bioenergy. Thus the identification of barriers to farmer adoption of perennial energy crops, and how these may be overcome is of key importance to policy makers intent on a significant increase in the use of bioenergy in the UK.

3.4 Research Approach: Theory of Planned Behaviour

For the first two papers, the Theory of Reasoned Action (TORA) (Ajzen & Fishbein, 1980) and its extension the Theory of Planned Behaviour (TPB) (Ajzen, 1991) provide the conceptual framework for exploring farmers' attitudes and intentions in respect of the adoption of perennial energy crops. Both theories have been widely used in agricultural research to understand barriers and drivers to the adoption of new technologies and practices (Garforth et al., 2004; Beedell & Rehman, 2000) and to estimate the likely scale of adoption of particular activities (Mattison & Norris, 2007).

According to the TORA, the intention to adopt a particular behaviour is a function of attitudes towards the behaviour and the subjective norm, that is the extent to which one is influenced by the views of other people regarding the behaviour (Ajzen & Fishbein, 1980).

Attitudes are a product of the extent to which one expects the behaviour to result in specific outcomes (outcome beliefs) and the importance of those outcomes (outcome evaluations). The subjective norm is a function of the perceived support of salient referents (people to whom respondents might turn for advice) towards the behaviour (subjective beliefs) and the motivation to comply with those beliefs. The TORA claims that the intention to perform a particular behaviour is a reliable indicator of actual future behaviour if the expressed attitude towards this behaviour and/or the perceived social pressure to do so correlate closely with the stated intent. A comparison of the strength of correlation of the attitude and subjective norm with the stated intent towards the adoption of SRC willow or miscanthus indicates which of the two components has greater influence on the farmers' decision relating to the adoption of these crops (Ajzen & Fishbein, 1980).

Theoretical developments in social psychology led to the Theory of Planned Behaviour (see Figure 1), an extension of the TORA that incorporates 'perceived behavioural control' as a measure of the extent to which people believe they are able to control the outcome (Ajzen, 1991). This followed studies suggesting that TORA performed poorly where the perceived efficacy of achieving the expected result was low - in which case the behaviour would not be attempted regardless of the strength of the attitudinal and social influences (Burton, 2004).

Perceived behavioural control is an individual's assessment of their own ability (control belief) to perform a particular behaviour and their capability (power of control). The TPB states that perceived behavioural control can also predict behavioural intent. The contribution of perceived behavioural control is assessed by comparing the strength of its correlation with intent with that of the other two causal components (Ajzen, 1991).

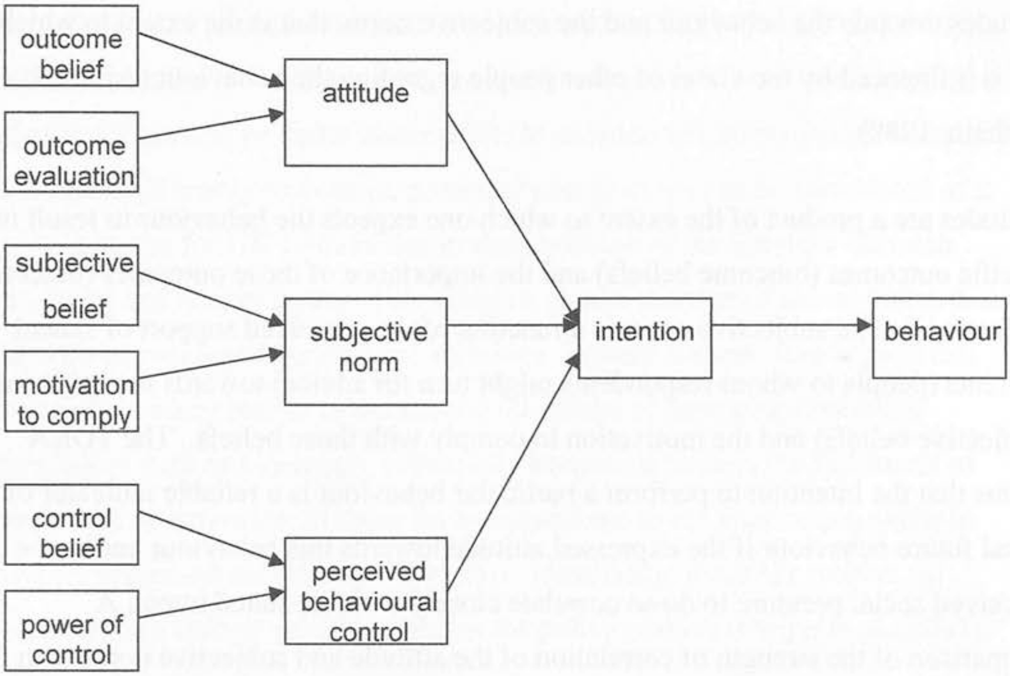


Figure 1: Theory of Planned Behaviour (Ajzen, 1991)

Of central importance within a TPB study is the principle of compatibility, that is "relations between attitudes and behaviours are maximally strong to the extent that their action, target, context, and time elements are assessed at the same level of generality or specificity" (Eagly and Chaiken, 1993). In this study the TPB is applied to predicting farmers' behaviour towards the adoption of perennial energy crops over the next five years.

3.5 Research Approach: Focus groups

The first stage of the research involves using focus groups to gather a range of statements from farmers relating to their attitudes to the adoption of perennial energy crops. Focus groups are distinguished from other methods of group interviewing, such as 'brainstorming' or Delphi groups, by the explicit use of the group interaction to produce data and insights that would be less accessible without the interaction found in a group (Morgan, 1988). According to Morgan (1988) 'focus groups are useful when it comes to investigating *what* participants think but they excel at uncovering *why* participants think as they do'

Focus groups have previously been used for TPB studies (Beedell & Rehman, 2000; Garforth et al., 2004), as they have the advantage of enabling data from a group of people to be gathered more quickly than through individual interviews, and they also permit the researcher to immediately follow-up participant statements in order to clarify responses.

However, there is also the risk that some participants may dominate proceedings, leading more reserved members to hold back.. It must also be borne in mind that the small number of participants mean that findings can't necessarily be generalised to wider populations. It is for this reason, as in this case, that focus groups are often used as a preliminary stage in a larger research program that includes a more representative survey of the population (Walker 1985).

Three groups, held in Thame (Oxfordshire), Bawtry (Nottinghamshire), and Scotlandwell (Fife), took place between November 2006 and January 2007. The locations were chosen for proximity to existing or proposed co-firing or dedicated biomass power plants. Participants were sought through a number of channels (producer groups, Farming and Wildlife Advisory Group (FWAG), National Farmers' Union of England and Wales (NFU) and SAC advisory service) with the intention being to get a broad mix of existing and potential growers of miscanthus and SRC willow.

The discussions were recorded and the output analysed by two researchers, grouping responses into key themes. The findings from this stage are reported in the first paper, 'Farm-level constraints on the uptake of perennial energy crops in the UK'.

3.6 Research Approach: Postal survey

The second stage involved using the identified outcome beliefs and salient referents in a structured questionnaire. Following a pilot survey, questionnaires were sent to 1500 farmers in three areas where SRC willow and miscanthus had already been planted under Defra's Energy Crops Scheme in England, and that were within 25 miles of either a co-firing or dedicated biomass power plant. It was decided that this would be preferable to a survey covering the whole of the UK, as in some areas there has been no development of perennial energy crops, co-firing or dedicated biomass power plant. By focusing on areas where there is an existing source of demand, it was considered that the questionnaires would be of more relevance to farmers. Within these areas, farmers were selected at random from a business directory. In all, 150 usable responses were received - a response rate of 10%.

Farmers were asked to score a response to the questions on a 5 point scale. These responses were numerically coded from -2 to +2 for analysis. Table 1 shows the question structure for each construct.

TPB Construct	Question Structure	Measurement scale
Behavioural intention	Are you intending to plant SRC willow on your farm in the next 5 years?	Certainly not, probably not, unsure, probably, certainly
Stated attitude	Choosing to plant SRC willow on my farm in the next 5 years would be a good decision	Strongly disagree, disagree, unsure, agree, strongly agree
Stated subjective norm	People whose opinions I value think I should plant SRC willow on my farm in the next 5 years	Strongly disagree, disagree, unsure, agree, strongly agree
Outcome evaluation	Do you agree or disagree with the following statements?	Strongly disagree, disagree, unsure, agree, strongly agree
Belief strength	How important are the following to you?	Unimportant, not very important, no opinion, important, very important
Subjective belief	Do you think the following would approve or disapprove of you growing SRC willow on your farm in the next 5 years?	Strongly disapprove, disapprove, unsure, approve, strongly approve
Motivation to comply	Would you follow the advice of the groups below in deciding whether or not to grow SRC willow on your farm in the next 5 years?	Very unlikely, unlikely, unsure, likely, highly likely
Perceived difficulty	How difficult would it be to grow SRC willow on your farm in the next 5 years?	Very difficult, difficult, unsure, easy, very easy
Perceived ability	How confident are you of being able to grow SRC willow on your farm in the next 5 years?	Not at all confident, not very confident, don't know, confident, very confident

Table 1: Question structure for the TPB survey

Farmers were also invited to add their own thoughts in a comments box at the end of the questionnaire. The findings from this stage are reported in the second paper, 'Farmer attitudes and intentions towards the adoption of perennial energy crops in the UK: An application of the Theory of Planned Behaviour'.

3.7 Research Approach: Farm-level linear programming model

The third paper abstracts from the uncertainties that are identified in the previous two papers, and looks at the level of financial return required to motivate farmers to adopt perennial energy crops under the assumption of a profit maximising decision maker, and in the absence of previously identified barriers.

While the literature on farmer decision making suggests numerous objectives beyond profit maximisation (Burton, 2004; Gasson, 1973), the modelling of 'rational economic man', for the purposes of this research, does allow for the identification of key messages about the existence of barriers to uptake.

A generic linear programming model for farm-level analysis, developed at the Scottish Agricultural College (SAC) was used to assess the likely uptake of perennial energy crops at different levels of gross margin. The model can be calibrated to represent any particular farm situation, in terms of basic resource endowments, and run using Visual Basic for Applications and Microsoft Excel Solver to simulate representative or real farm situations. The model has been used in various studies, e.g. Revell and Oglethorpe (2003), to analyse the economic impacts of policy developments on farm businesses, particularly relating to how enterprise substitutions may occur. The model incorporates all major cropping and livestock activities carried out on UK farms and can thus be calibrated for all mainstream farming types (University of Cambridge, 2005).

The model was used by University of Cambridge (2005) to predict uptake of perennial energy crops across four of the major farm types (cereal farms, mixed farms, general cropping farms, cattle and sheep (lowland) farms). Each of these farm types were split into three size groups to enable further analysis of possible differential levels of uptake (see Table 2). Within rotational constraints, the simple analysis was that, all else being equal, SRC willow and miscanthus would have to provide gross margins greater than those for alternative crops to be adopted. Costs, prices and resource requirements for conventional activities were obtained from the 2002/03 edition of the Farm Management Handbook (SAC, 2002).

Farm Type	Size	Total area farmed (ha)
Cereal	Small	59
	Medium	143
	Large	392
Mixed	Small	91
	Medium	125
	Large	286
General cropping	Small	68
	Medium	88
	Large	359
Cattle & sheep (lowland)	Small	80
	Medium	121
	Large	205

Table 2: Farm types used in modelling

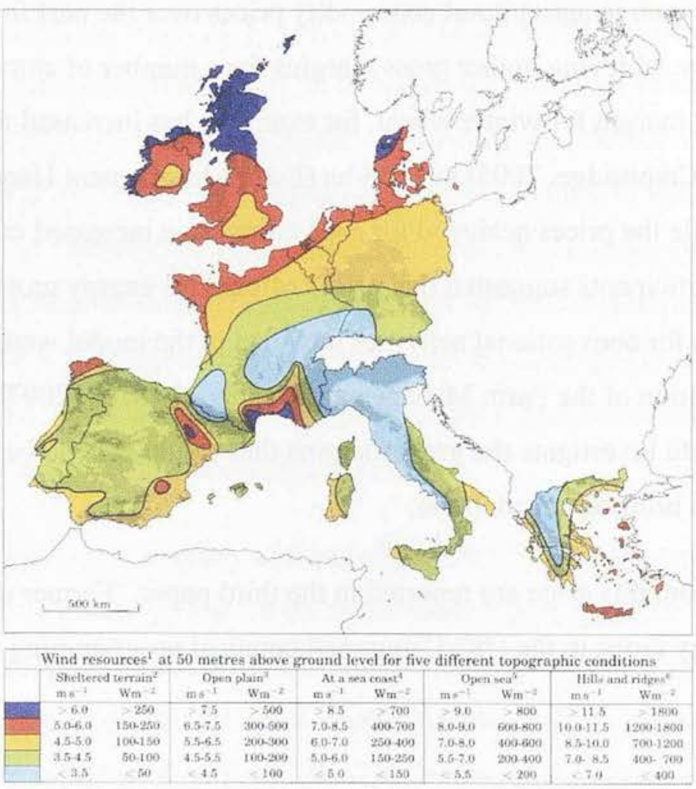
With a global boom in agricultural commodity prices over the past few years, UK farmers are now achieving higher gross margins for a number of conventional crops. A typical gross margin for winter wheat, for example, has increased from £301/ha (University of Cambridge, 2005) to £738/ha (Farm Management Handbook, 2007/08). While the prices achieved for such crops have increased considerably, the focus group participants suggested that prices offered for energy crops have failed to keep up. Prices for conventional activities included in the model were updated using the 2007/08 edition of the Farm Management Handbook (SAC, 2007b), and the analysis re-run to investigate the gross margins that would have to be achieved by energy crops to bring about adoption.

The findings from this stage are reported in the third paper, 'Farmer uptake of perennial energy crops in the UK: Using mathematical programming to model supply'.

4.0 Wind Power: Background and Research Approach

4.1 Technical potential of wind power in the UK

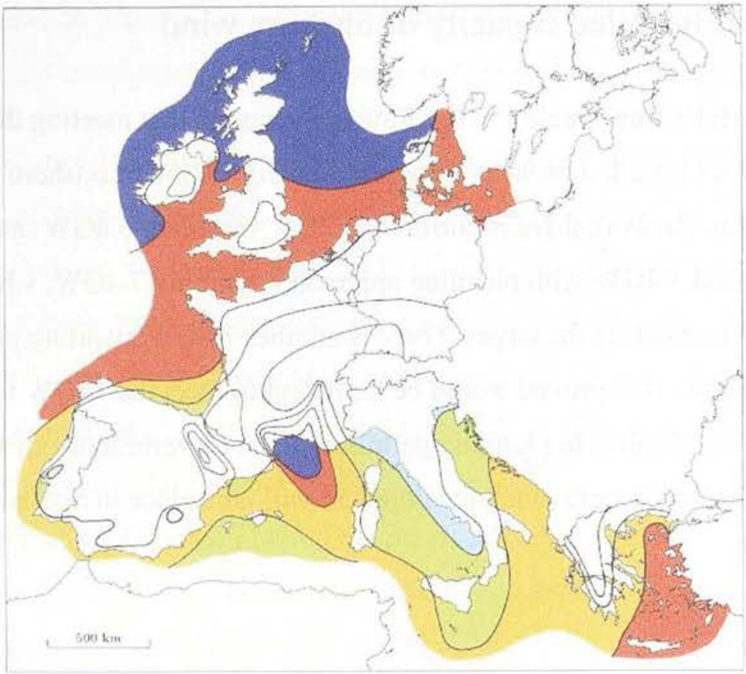
The UK has some of the best wind resources in Europe, with high average wind speeds and good reliability (Sustainable Development Commission, 2005). Figure 2 shows the onshore wind resources, and Figure 3 shows the offshore wind resource. It is clear from these figures that of all the countries in the UK, Scotland has the greatest potential for wind energy.



Wind resources[1] at 50 metres above ground level for five different topographic conditions

	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}
🟪	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
🟥	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
🟨	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
🟩	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
🟦	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

Figure 2: European onshore wind resources. Source: Riso National Laboratory, Denmark



Wind resources over open sea (more than 10 km offshore) for five standard heights										
	10 m		25 m		50 m		100 m		200 m	
	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}
🟦	> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
🟥	7.0-8.0	350-600	7.5-8.5	450-700	8.0-9.0	600-800	8.5-10.0	650-1100	9.5-11.0	900-1500
🟨	6.0-7.0	250-300	6.5-7.5	300-450	7.0-8.0	400-600	7.5- 8.5	450- 650	8.0- 9.5	600- 900
🟩	4.5-6.0	100-250	5.0-6.5	150-300	5.5-7.0	200-400	6.0- 7.5	250- 450	6.5- 8.0	300- 600
🟦	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300

Figure 3: European offshore wind resources. Source: Riso National Laboratory, Denmark

The importance of high average wind speeds becomes clear when considering the relationship between wind speed and power output from wind turbines. The power output is approximately proportional to the cube of the wind speed (Manwell et al., 2002), which means in practice that a doubling of the average wind speed from $4ms^{-1}$ to $8ms^{-1}$ leads to an eight-fold increase in theoretical power output. This makes the United Kingdom, and Scotland in particular, a very attractive location for developers, as the primary support mechanism, the Renewables Obligation, is based on output rather than installed capacity (Ofgem, 2010).

4.2 Current installed capacity of onshore wind

The Government's Renewable Energy Strategy suggests that meeting the 2020 target would require an installed capacity of approximately 14GW of onshore wind (DECC, 2009a). Onshore there is currently 3.2GW installed, 0.8GW under construction, and 3.4GW with planning approval – totalling 7.4GW, which is just over half way to meeting the target. There is another 7.4GW awaiting planning permission, which, if approved would be sufficient to meet the 14GW target (BWEA, 2009b). Subject to planning permission, the Government expects that a large proportion of onshore wind development will take place in Scotland (BERR, 2008).

4.3 Planning as a barrier to the development of windfarms

It is recognised that a number of non-financial barriers have restrained renewables development in the UK. These include, in particular, planning issues, access to the electricity grid, and supply chain constraints (BERR, 2008). Of these, planning is seen by a number of commentators as being 'absolutely critical' as it affects both the building of new generation capacity and the associated electricity grid. For wind farms, grid connectivity can be especially problematic as the windiest places are often remote from the existing grid (House of Lords, 2008).

Evidence submitted to a House of Lords Committee by Scottish and Southern Energy indicated that a new onshore windfarm would take 10 years to develop and build, with half of that time spent in planning (House of Lords, 2008). The UK Renewable Energy Strategy consultation document recognises that the Planning Bill will not bring about a sufficient change to meet the 2020 target (BERR, 2008; House of Lords, 2008), and the recent House of Lords Committee report finds that:

"Without an effective planning system we do not believe that the UK will be able to meet its target. It is fundamental that appropriate procedures are put in place to ensure that new generation plant and grid infrastructure can be increased, subject to local considerations. This means that developers must be able to have confidence in the reliability and consistency of the planning system" (House of Lords, 2008).

The recently formed Infrastructure Planning Committee (IPC), set up under the 2008 Planning Act is intended "to make the application process for nationally significant infrastructure projects faster and fairer" (IPC, 2010). The IPC is the planning authority for onshore proposals over 50MW, and offshore proposals over 100MW, working to implement the approach as outlined in the Draft National Policy Statement for Renewable Energy Infrastructure (DECC, 2009b), and the Draft Overarching National Policy Statement for Energy (DECC, 2009c). The approach outlined in these draft National Policy Statements should, at the least, mean that establishing the need for more renewables would not need to be addressed anew at every planning enquiry (House of Lords, 2008).

However, there are concerns that with the threshold for consideration by the IPC set at 50MW, and the British Wind Energy Association anticipating that the majority of schemes will be below this size, there will be no significant change in the rate at which planning decisions are progressed. These smaller applications will still be, as argued by one developer, Ecotricity, 'subject to the same procedure as a home extension', with the process involving the same people (House of Lords, 2008).

Moreover, guidance for both the IPC and local planning authorities on assessing the landscape and visual impact arising from wind farm developments, still relies on an approach that is arguably open to much subjective interpretation. The techniques for evaluation have not changed from those included in guidance from the Scottish Executive in 2007, as outlined below.

4.4 Planning concerns: Landscape impact versus carbon emissions

In addition to their remoteness from grid infrastructure, the places that are most attractive in terms of the wind regime are often precisely those exposed upland areas which are valued for their scenic qualities and which are often ecologically sensitive. Expansion of wind power will therefore bring a number of associated costs and benefits, and it is the role of the planning authorities to strike the appropriate balance in considering which developments to permit.

Guidance from the Scottish Executive states that:

"Consideration of the significance of any adverse impacts of a renewable generation proposal should have regard to the projected benefits of the proposal in terms of the scale of its contribution to addressing climate change through its contribution to the Scottish Executive's targets for renewable energy. A relevant consideration should be whether such a scale of renewables contribution could be realised with fewer or lesser impacts in a different location or through several smaller projects" (Scottish Executive, 2007).

The Scottish Executive's guidance does not, however, outline how to achieve the appropriate balance. While the methodology for landscape and visual impact assessments is well developed (University of Newcastle, 2002; Landscape Institute & Institute for Environmental Management and Assessment, 2002), the question remains as to how tonnes of avoided carbon dioxide emissions should be compared against the results of a visual impact assessment that presents impact scores using an ordinal scale? In the absence of a common scaling denominator there would appear to be significant challenges to establishing, in a transparent and consistent manner, whether a project's costs outweigh the benefits, or moreover, to compare competing projects and rank them.

4.5 Research Approach: Cost Benefit Analysis

The fourth paper in this thesis, 'An economic assessment of wind power generation in Scotland, including externalities', uses a standard UK Government approach to cost-benefit analysis as outlined in the Treasury's Green Book. This applies landscape valuation techniques to establish a monetary value for the visual disamenity arising from the windfarm, and also uses Government carbon valuation guidance to place a monetary value on avoided carbon emissions. In so doing, the paper explores how the apparently intangible non-market impacts can be quantified, alongside the financial costs and benefits, to establish the extent of the overall cost or benefit to society of the proposal. The potential for wider use of such an approach to more effectively identify and quantify the impacts arising from onshore windfarms is considered. Enhancing understanding of the relative costs and benefits of schemes, using such techniques, is argued to have a number of significant advantages over the current approach, not least of which could be the achievement of targets in a way that is most cost-effective in societal terms.

5.0 References

ADAS, 2003. The Mid-Term Evaluation of the England Rural Development Programme (ERDP): Energy Crop Scheme. Available at http://www.defra.gov.uk/erdp/pdfs/midterm/cs_ecs_3.pdf (accessed August 2007)

Ajzen, I., 1991. The theory of planned behaviour, Organizational Behaviour and Human Decision Processes, 50, 179-211.

Ajzen, I. & Fishbein, M., 1980. Attitudes, Personality and Behaviour, Open University Press, Milton Keynes.

Beedell, J. & Rehman, T., 2000. Using social-psychology models to understand farmers' conservation behaviour. Journal of Rural Studies 16, 117-127.

BERR, 2008. Consultation for a UK Renewable Energy Strategy, Department for Business, Enterprise and Regulatory Reform, 26 June 2008.

Burton, R.J.F., 2004. Reconceptualising the 'behavioural approach' in agricultural studies: a socio-psychological perspective, Journal of Rural Studies 20, 359-371.

BWEA, 2009. Press release 20th October 2009: 'Wind farm planning approvals by local councils slump to record new low of 25%', available at http://www.bwea.com/pdf/press/PR20091020_25pc_approval.pdf

(accessed January 2010).

Country Guardian, 2009. Website homepage, available at http://www.countryguardian.net/ (accessed November 2009).

DARDNI, 2007. Renewable Energy Action Plan, Department of Agriculture and Rural Development Northern Ireland, January 2007. Available at http://www.dardni.gov.uk/renewable-energy-action-plan-2.pdf (accessed July 2007)

DECC, 2009a. The UK Renewable Energy Strategy, Department of Energy & Climate Change, July 2009.

DECC, 2009b. Draft National Policy Statement for Renewable Energy Infrastructure (EN-3), November 2009. Available at http://data.energynpsconsultation.decc.gov.uk/documents/npss/EN-3.pdf (accessed March 2010).

DECC, 2009c. Draft Overarching National Policy Statement for Energy (EN-1), November 2009. Available at http://data.energynpsconsultation.decc.gov.uk/documents/npss/EN-1.pdf (accessed March 2010).

Defra, 2006. Creating Value from Renewable Materials: A strategy for non-food crops and uses - Two year progress report, Department for Environment, Food and Rural Affairs, November 2006. Available at http://www.defra.gov.uk/farm/crops/industrial/pdf/nfc-progress-0611.pdf (accessed July 2007)

Defra, 2007. UK Biomass Strategy. Department for Environment, Food and Rural Affairs, May 2007.

DTI, 2003. Renewables Innovation Review, Department of Trade and Industry. Available at http://www.dti.gov.uk/files/file22017.pdf (accessed July 2007)

DTI, 2007. Meeting the Energy Challenge: A White Paper on Energy. Department of Trade & Industry, May 2007.

E4Tech, 2009. Biomass Supply Curves for the UK, March 2009. Available at http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/res/res.aspx (accessed November 2009).

Eagly, A. Chaiken, S., 1993. The Psychology of Attitudes, Harcourt Brace Jovanovich, San Diego.

European Parliament and Council of the European Union, 2009. Directive of the European Parliament and of the Council on the Promotion of the Use of Energy from Renewable Sources, PE-CONS 3736/08, Brussels, 26 March 2009. Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF

(accessed May 2009).

Garforth, C., Rehman, T., McKemey, K., Tranter, R.B., Cooke, R.J., Yates, C.M., Park, J.R., and Doward, P.T., 2004. Improving the design of knowledge transfer strategies by understanding farmer attitudes and behaviour. Journal of Farm Management 12, 17-32.

Gasson, R., 1973. Goals and values of farmers, Journal of Agricultural Economics, 24, 521-537.

House of Lords, 2008. The Economics of Renewable Energy, Volume 1: Report. Select Committee on Economic Affairs, 4th Report of Session 2007-08. Available at http://www.publications.parliament.uk/pa/ld200708/ldselect/ldeconaf/195/195i.pdf (accessed January 2010)

IPC, 2010. Infrastructure Planning Commission website. Available at http://infrastructure.independent.gov.uk/?page_id=5 (accessed March 2010).

Landscape Institute & Institute for Environmental Management & Assessment (LI-IEMA), 2002. Guidelines for Landscape and Visual Impact Assessment, 2nd Edition. Spon Press, London.

Manwell, J.F., McGowan, J.G. and Rogers, A.L., 2002. Wind energy explained: Theory, design and application. John Wiley and Sons, New York.

Mattison, E. H. A. & Norris, K., 2007. Intentions of UK Farmers toward Biofuel Crop Production: Implications for Policy Targets and Land Use Change. Environmental Science & Technology, Vol 41, 16, 5589-5594

Meijer, I. S. M., Hekkert, M. P. & Koppenjan, J. F. M., 2007. The influence of perceived uncertainty on entrepreneurial action in emerging renewable energy technology; biomass gasification projects in the Netherlands. Energy Policy 35, 5836-5854

Morgan L. D., 1988. Focus groups as qualitative research, Sage Publications, Newbury Park, CA.

Ofgem, 2010. Renewables Obligation webpage. Available at http://www.ofgem.gov.uk/Sustainability/Environment/RenewablObl/Pages/RenewablObl.aspx (accessed March 2010)

RELU, 2009. Policy and Practice Note No. 9, Assessing the social, environmental and economic impacts of increasing rural land use under energy crops, Rural Economy and Land Use Programme, September 2009. Available at http://www.relu.ac.uk/news/policy%20and%20practice%20notes/Karp/Karp.pdf (accessed November 2009).

RCEP, 2000. Energy - The Changing Climate: The 22nd Report by the Royal Commission on Environmental Pollution, London.

RCEP, 2004. Biomass as a renewable energy source: a limited report by the Royal Commission on Environmental Pollution, London.

Revell, B. and Oglethorpe, D., 2003. Decoupling and UK Agriculture: A whole farm approach. An appraisal of the impact on the livestock sector, commissioned by Defra.

SAC, 2002. Farm Management Handbook 2002/2003, Scottish Agricultural College, Edinburgh.

SAC, 2007a. Commercial viability of alternative non food crops and biomass on Scottish Farms - a special study supported under SEERAD Advisory Activity 211, March 2007. Available at http://www.sac.ac.uk/mainrep/pdfs/nonfoodbiomass.pdf (accessed July 2007).

SAC, 2007b. Farm Management Handbook 2007/2008, Scottish Agricultural College, Edinburgh.

Scottish Executive, 2007. Scottish Planning Policy 6: Renewable Energy.

http://www.scottishexecutive.gov.uk/Resource/Doc/171491/0047957.pdf (accessed April 2007)

Sherrington, C., Bartley, J. and Moran, D., 2008. Farm-level constraints on the domestic supply of perennial energy crops in the UK. Energy Policy 36, 2504-2512.

Strawson, J., 2005. Energy Crops and the Market for Biomass in the UK. Nuffield Farming Scholarships Trust, January 2005.

Sustainable Development Commission, 2005. Wind power in the UK: A guide to the key issues surrounding wind power development in the UK. London.

University of Cambridge, 2005. Farm level economic impacts of energy crop production, Final Report to Defra, August 2005.

University of Newcastle, 2002. Visual Assessment of Windfarms Best Practice. Scottish Natural Heritage Commissioned Report F01AA303A

Walker, R. L., 1985. Applied Quantitative Research, Gower,VT.

Welsh Assembly Government, 2007. Personal communication from Vicky Davies, Rural Development Adviser, Technical Services Division, Welsh Assembly Government, Llandrindod Wells.

Woods, J., and Black, M., 2008. Local land use change impacts and opportunities: Contribution to the Gallagher Report, May 2008. Available at http://www.renewablefuelsagency.gov.uk/sites/renewablefuelsagency.gov.uk/files/_documents/Themba_Local_land_use_change_impacts_and_opportunities.pdf

(accessed January 2010).

Chapter 2: Farm-level constraints on the domestic supply of perennial energy crops in the UK

The research presented in this chapter has been published as Sherrington, C., Bartley, J. and Moran, D., 2008. Farm-level constraints on the domestic supply of energy crops in the UK, Energy Policy 36, 2504 - 2512.

Justin Bartley of the Institute for European Environmental Policy was responsible for arranging venues for the three focus groups, recruiting farmers, and writing up his own notes from the meetings which were then cross-checked by the lead author, to ensure that his own reporting of the findings had covered all the relevant points. The lead author prepared the questions for the focus groups, and wrote up notes based on the farmers' statements, which were also recorded on an audio tape. To enable the lead author and Justin Bartley to concentrate on noting responses, the focus groups were facilitated by an independent consultant. The lead author attended the first focus group, and wrote up his notes from that group having listened again via the recording. The lead author did not attend the next two focus groups, but listened through twice to the recordings, and checked his notes against those of Justin Bartley. The lead author wrote the paper, including the introduction to the relevant agricultural and energy policies, consideration of levels of energy crop uptake to date and the key recommendations. Dominic Moran reviewed the final paper before submission.

Abstract

There are a number of estimates of the land area that could potentially be dedicated to perennial energy crops such as Short Rotation Coppice (SRC) Willow and Miscanthus in the UK, but little is known about how farmers will respond to the opportunities presented by these relatively novel crops. Perennial energy crops face competition from other, arguably more flexible, uses of farmland, and if not seen as attractive propositions to individual farmers, they will not be grown. Farmers' decisions are therefore a key constraint on potential supply. This paper reviews the policy background and considers whether policy is based on any consideration of

likely supply response, before presenting outcomes of focus groups composed of farmers who already grow or are considering growing perennial energy crops. There appear to be a number of barriers to adoption. In addition to concerns over the security of contracts, the current high wheat price increases the opportunity cost of committing land to perennial energy crops. There are also worries about the impact of willow roots on field drains and the cost of returning the land to other uses. This paper outlines a number of issues of importance to policy makers and suggests future research needs.

6.0 Introduction

The twin concerns of climate change and energy security have increased attention on renewable energy. In the UK, these factors have combined with an agricultural reform process that has highlighted the need for farmers to diversify away from traditionally supported arable and livestock products. Accordingly, the UK Government has in recent years demonstrated an increasing enthusiasm for the use of biomass as a source of electricity, heat and transport fuel. The UK Biomass Strategy (Defra, 2007a) states the Government's intention to bring about a major expansion in both the supply and use of biomass in the UK, indicating that biomass will have a central role to play in meeting the EU target of 20% renewable energy by 2020 (Defra, 2007a).

While the UK Biomass Strategy proposes an increase in the use of biomass for heat, electricity and biofuels, beyond acknowledging the 10% minimum share of biofuels target for 2020 (Council of the European Union, 2007) it does not include specific targets for particular feedstocks or end uses. It does, however, outline what the UK Government considers to be the potential UK supply of biomass feedstocks up to 2020.

This paper will argue that for perennial energy crop feedstocks such as Short Rotation Coppice (SRC) Willow and Miscanthus, the likely level of supply will be considerably below the theoretical potential unless a number of barriers to their adoption by farmers are overcome.

The paper adds to a growing literature on perennial energy crops and the development of biomass energy in the UK, Europe and beyond (Rosenqvist & Dawson, 2005; Skytte et al., 2006; Charles et al., 2007). While there has been much focus on techno-economic aspects and theoretical supply chain potential (Andersen et al., 2005; Ericsson & Nilsson, 2005; Styles & Jones, 2007), broad stakeholder opinion (Upham & Speakman, 2007), and wider public policy implications (Charles et al., 2007), relatively little is known about how individual farmers will choose to respond to the opportunities presented by these relatively novel crops. Strawson (2005), writing from the perspective of a farmer with land already committed to SRC Willow, and at a time when returns from alternative activities were much lower than at present, offers a relatively upbeat assessment of the potential attractiveness of the crop. However, in the context of a significant and ongoing global rise in the price of agricultural commodities such as wheat (FAO, 2007), a changing agricultural policy landscape in the EU (European Commission, 2007) , and a UK renewable energy support mechanism that is under review (DTI, 2007a) , it is important to gain an up-to-date understanding of farmers' attitudes and behavioural intentions towards the adoption of perennial energy crops.

The paper is structured as follows. The next section outlines the framework for considering farm-level constraints, and is followed by an introduction to UK biomass resources. A number of estimates of the theoretical potential of perennial energy crops are discussed, and compared with the recent level of adoption. There follows an outline of the policies intended to stimulate the use of biomass in the energy mix, along with details of farm level support for the cultivation of perennial energy crops. The results of a series of focus groups with farmers discussing adoption of perennial energy crops are then outlined, with consideration of the implications of the findings for policy-makers.

6.1 Framework for considering farm-level constraints on the adoption of perennial energy crops

Perennial energy crops can be considered as a novel enterprise for UK farmers both in terms of their cultivation, and in their position at the interface between agricultural and energy policy. This brings a greater number of uncertainties than exist with conventional agricultural activities. Several authors have argued that uncertainty is a key barrier to the successful uptake of emerging renewable technologies such as bioenergy (Kemp et al., 1998; Foxon et al., 2005), principally because it hinders the fulfilment of entrepreneurial activities (Jacobsson & Bergek, 2004). In order for entrepreneurs to act, motivation needs to outweigh perceived uncertainty. Therefore, identifying dominant sources of uncertainty can deliver valuable insights for policy makers (Meijer et al., 2007)

In addition, many systems such as energy and agriculture are characterised by lock in and resistance to change (Unruh, 2000), through technological, institutional and social path dependency, resulting in a variety of barriers for new innovations such as energy crops and bioenergy (van der Laak et al., 2007). Much work has been done in the field of Strategic Niche Management (SNM) to identify what makes for a successful innovation, or to explain the failure of other innovations (van der Laak et al., 2007; Raven, 2005). The level of analysis in SNM is typically a series of projects such as pilot plants and demonstration plants, covering a substantial number of projects over periods up to 30 years. This yields useful insights for policy makers, and emphasises the importance of shaping expectations of stakeholders, building social networks, and of a good learning process (van der Laak, 2007). In addition, lessons for policy makers can be drawn from research into technological innovation in the energy sector. A key insight here is that identifying market barriers that stand in the way of widespread implementation of new technologies, and then designing ways to overcome these, while concurrently enhancing learning gains, are crucial to successful energy innovation (Sagar & van der Zwaan, 2006).

Thus the identification of barriers to farmer adoption of perennial energy crops, and how these may be overcome is of key importance to policymakers intent on a significant increase in the use of bioenergy in the UK.

For this study, the Theory of Reasoned Action (TORA) (Ajzen & Fishbein, 1980) and its extension the Theory of Planned Behaviour (TPB) (Ajzen, 1991) provide the conceptual framework for exploring farmers' attitudes and intentions in respect of the adoption of perennial energy crops. Both theories have been widely used in agricultural research to understand barriers and drivers to the adoption of new technologies and practices (Garforth et al., 2004; Beedell & Rehman, 2000) and to estimate the likely scale of adoption of particular activities (Mattison & Norris, 2007)

The first stage of the research involves using focus groups to gather a range of statements from farmers relating to their attitudes to the adoption of perennial energy crops. It is the findings from this first stage that are reported in this paper.

6.2 Potential biomass resources in the UK

There are a number of possible sources of biomass for energy in the UK, including forestry, wood waste, conventional agricultural crops such as wheat and oilseed rape, straw, perennial energy crops, and agricultural waste (RCEP, 2004: Defra, 2007a).

To increase available biomass, Defra (2007a) favours obtaining an additional 1 million dry tonnes of wood per annum from woodland and wood waste, more use of manures and slurries, and a substantial growth in uptake of perennial energy crops such as SRC Willow and Miscanthus. Of these sources, it is the anticipated change in levels of perennial energy crops that is most dramatic. The technical potential of energy crops is estimated to be 17.2 TWh [5] (1.48 Mtoe) [6], while current availability is 0.07-0.09 Mtoe (Defra, 2007a). Such an increase would represent an almost 20-fold increase in the level of supply, albeit from a low level.

To reach the technical potential of perennial energy crops by 2020 (Defra, 2007a), would require 350,000 hectares (ha) of land, which is roughly 6.5% of UK arable and set-aside land, assuming an average annual yield of 9odt/ha [7] (Defra, 2007a). The Renewables Innovation Review (DTI, 2003b) suggests this is a realistic area once a number of constraints, including competition from other markets, are taken into account.

Defra expectations for perennial energy crops are somewhat lower than proposals from the Royal Commission on Environmental Pollution (RCEP) biomass report (RCEP, 2004). Focusing on the potential contribution of biomass towards a 60% reduction in UK CO_2 emissions by 2050 (RCEP, 2000), it recommends that by 2050 up to 16 Gigawatts (about 12%) of UK energy should come from biomass. To supply this, about 70 million tonnes of wood would be required per year. If derived from energy crops at an assumed average yield of 10 odt/ha/yr, this would need 7 million hectares.

However, assuming the availability of a certain amount of forestry material and straw, a scenario is outlined where the land required for energy crops would rise from 1 million hectares in 2020 to 5.5 million hectares in 2050 (RCEP, 2004).

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[5] Terrawatt hours (One terrawatt is a trillion, or 10^{12} watts)

[6] Million tonnes of oil equivalent

[7] Oven dried tonnes

Other estimates include an assumption by the Carbon Trust (2005) that 680,000 ha (roughly equal to set-aside) could be available for woody energy crops. This study notes that estimates of the land area that could be used for energy crops vary greatly, emphasising the somewhat arbitrary nature of their assumption (Carbon Trust, 2005).

The key feature of all these estimates is the assumptions about farmer behaviour. They take for granted that sufficient farmers will choose to grow perennial crops up to the level of the constraints that they identify. However, this assumption does not seem to be supported by experience to date.

Defra's Energy Crops Scheme, which provides establishment grants for SRC Willow and Miscanthus, along with support for developing SRC producer groups, had a number of objectives for the first period of the English Rural Development Programme (ERDP) (2000 - 2006). These included the planting, by 2006, of 16,700ha of SRC and 5000ha of Miscanthus in England (ADAS, 2003). When the scheme closed to applications, in July 2006, only 1,180 hectares of SRC and 3,356 ha of Miscanthus had been planted (Defra, 2006a), representing 20% of the target level. This does, however, mark an improvement over the uptake by the half-way point in 2003, where only 2% of the SRC target and 3% of the Miscanthus target had been planted (ADAS, 2003).

More recently, there has been an increase in interest in the payments, with applications for planting in 2007 due to take the area of Miscanthus to 12,627ha, and SRC to 2,600ha in England (Defra, 2006a).

In Scotland, the area planted or approved for planting up until the end of 2006 is 300ha. Current applications for planting in 2007 and 2008 amount to around 600ha (SAC, 2007). In Northern Ireland, 400ha of SRC have been planted or approved for planting to date, and a further 410ha have been approved for the 2007 planting year (DARDNI, 2007), while in Wales there is currently 40ha of SRC and 72ha of Miscanthus (Welsh Assembly Government, 2007).

The latest published figure for the total area of perennial energy crops in the UK is 15,546ha for SRC willow and miscanthus combined (Defra, 2007a).

6.3 Policies intended to stimulate the use of biomass in the UK energy mix

6.3.1 Renewables Obligation

The Renewables Obligation (RO) is the UK Government's key policy mechanism for increasing the proportion of electricity derived from renewable sources. Under the scheme, there is a mandatory requirement for UK electricity suppliers to source a growing percentage of electricity from eligible renewable generation capacity. Suppliers are required to produce evidence of their compliance with this obligation to the Office of Gas and Electricity Markets (OFGEM). Evidence can be via certificates, referred to as Renewable Obligation Certificates (ROCs), which are currently worth approximately £47/MWh (NFPA, 2007).The target is 10% of UK electricity from renewable sources by 2010, with an aspiration to reach 20% by 2020 (DTI, 2007a). When introduced in 2002, there was debate as to whether co-firing of energy crops[8] with coal should be eligible for receiving ROCs. It was decided that co-firing should be eligible, in order to stimulate the development of energy crop supply chains (DTI, 2006b, Ilex Energy Consulting, 2003), but with restrictions, intended to prevent co-firing swamping the market for ROCs. A 25% cap was placed on the proportion of a supplier's obligation that could be met from co-fired ROCs;

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[8] An energy crop as currently defined by the Office of Gas and Electricity Markets (OFGEM) is a plant crop planted after 31 December 1989 grown primarily for the purpose of being a fuel or which is either Miscanthus, SRC Willow or SRC Poplar (OFGEM, 2007). Thus annual crops such as wheat and rapeseed can be co-fired as energy crops as long as they are grown specifically for the purpose. However within the RO the focus for co-firing has been on SRC Willow or Miscanthus (Ilex Energy Consulting, 2003)

from 2006 at least 75% of the biomass must be from energy crops; and co-firing would cease to be eligible by 2011.

However, the majority of co-firing has been of imported bio-wastes such as olive pits and palm kernels (IPA Consulting, 2006), while energy crops represent less than 0.3% by weight of all co-fired biomass.

In 2003, The Renewables Obligation (Amendment) Order Statutory Consultation noted that minimal planting of energy crops had taken place, with industry arguing that this was in part due to overly restrictive rules on co-firing in the Obligation; in particular that co-firing should be permitted only until 2011 (DTI, 2003a). It was therefore recommended that the requirement to co-fire a proportion of energy crops should be delayed from 2006 to 2009 to allow more time for planting and cropping (DTI, 2003a).

In addition, the date for co-firing to be phased out of the RO was postponed until 2016, and the energy crop requirements were relaxed (25% requirement in 2009, 50% in 2010, and 75% in 2011). Meanwhile the overall cap on co-firing was reduced (10% from 2006 and 5% from 2011) (DTI, 2006a).

The proposed changes were intended to enable the creation of a market for energy crops of up to 680,000 odt per annum, generating 1.26 TWh per annum, this being 75% of the 5% of the Obligation in the period 2011-16 (DTI, 2003a). By amending the start and end-dates for energy crop co-firing, it was intended to allow farmers three full cropping cycles for SRC planted in the spring of 2005 making this a much more attractive option in terms of establishing a market for energy crops (DTI, 2003a).

It was, however, argued at the time that extending the eligibility of co-firing would not provide the necessary stimulus to energy crop development, and that co-firing would likely displace investment in specialist energy crop combustion plants (Campbell Carr, 2003).

In the run up to the introduction of the 10% cap in April 2006, a number of concerns were raised about a 'cliff-edge' in co-fired ROC prices. This was cited as a reason why independent generators, in particular, had failed to sign up to long term supply contracts with farmers (Pöyry Energy Consulting, 2006). In addition, the impending lowering of the cap raised concerns about reducing the contribution of co-firing to the abatement of CO_2 emissions from fossil fuel plant. With the Government considering electricity generation from coal likely to remain an important part of the overall generating mix, it was considered appropriate to abate carbon emissions from coal fired plant as much as possible (DTI, 2006b). A report commissioned by the UK Government (Themba Technology, 2006) found that greenhouse gas (GHG) emission reductions from co-firing can be substantial for a very wide range of biomass fuels, whether UK-based or imported, and including both biomass residues and energy crop feedstocks (DTI, 2006b).

The report also found that waste or co-product materials tend to have lower GHG emissions per unit of energy over their lifecycle than dedicated energy crops (Themba Technology, 2006), leading to calls for a removal of government subsidies for dedicated energy crops along with the minimum requirement for energy crops as part of the co-firing cap (Scottish and Southern Energy, 2006). This position has not gone unchallenged; a critique of the Themba report has argued that a number of assumptions lead to a significant underestimate of the sustainability benefits derived from energy crops, particularly SRC (Alker and Miller, 2006).

As a result of the Themba analysis, and following stakeholder consultation, the Government announced in the Energy Review Report that co-firing should be encouraged to play a long-term role in reducing the carbon emissions from fossil fuel plants (DTI, 2006b). Thus, there has been a change in emphasis from co-firing being necessary to bring on the development of energy crops, to co-firing itself being an important source of reducing carbon emissions.

A further amendment to the RO has meant that since April 2007, ROCs awarded for the co-firing of energy crops do not contribute to a supplier's 10% co-firing limit (DTI, 2007a). It was argued that this would create an additional market for energy crops and so remove the need for the minimum energy crop percentages that would have been required from 2009 onwards (Lords Hansard, 2007). However, this has been met with scepticism and disapproval from a number of representatives of suppliers of energy crop feedstocks (Country Land and Business Association, 2006; Bical, 2006)

At present the RO is 'technology neutral', awarding ROCs for every MWh of electricity produced from any eligible renewable source. This is subject to change following a consultation where it is proposed that ‘banding’ be introduced from April 2009 to provide varying levels of support to different technologies. This is to encourage a greater diversity of renewable technologies and give greater support for those technologies that are currently less cost-effective. Under the amended Obligation, the cap on co-firing will be removed, 1 ROC will be awarded for every MWh from co-firing energy crops, while 2 ROCs will be awarded for every MWh from energy crops in dedicated biomass burners or in combined heat and power (CHP) (DTI, 2007a). Co-firing of regular (non-energy crop) biomass, considered an established technology, will receive a reduced level of support of 0.25 ROCs per MWh.

It is unclear whether these changes will provide sufficient stimulus for the development of a domestic supply of SRC and Miscanthus. It is argued by the National Farmers’ Union (NFU) of England and Wales that the minimum percentage requirement for energy crops is the most effective way to create long term demand, and that relying on differential ROC banding provides a less secure market and thus less incentive for farmers to plant a long term crop (NFU, 2006).

A further question is whether energy crops used for co-firing or in dedicated plant will actually be SRC Willow and Miscanthus, as the precise conditions required for a crop to count as an energy crop under the OFGEM definition are still subject to some uncertainty (Rosillo-Calle and Perry, 2006)

The NFU is keen that the OFGEM definition of energy crops should not restrict the use of annual crops, and they argue that it is absurd that a crop used to produce biofuel under the Renewable Transport Fuels Obligation (RTFO) could have its co-product classified as not being an energy crop under the RO if evidence was not available to demonstrate that it was always intended for energy use (NFU, 2006).

Scottish Power believe the definition of energy crops should be extended to include all energy crop types such as wheat and other grains (Scottish Power, 2006).

Indeed, a DTI report suggests that while most energy crops planted are SRC and Miscanthus, 'future expansion will probably occur with annual crops, which have the advantage of being much more compatible with agricultural practices and are finding considerable favour with farmers/growers' (DTI, 2007b).

As far as the Renewables Obligation is concerned, it does appear that despite the recent banding proposals, the development of supply chains for Miscanthus and SRC Willow, once a key aim within the RO, has become a lower priority.

6.3.2 Climate Change Levy

In addition to funding received through the Renewables Obligation, generators of renewable energy receive a levy exemption certificate (LEC) from the Climate Change Levy (CCL) for each MWh of renewable electricity produced. This provides an additional, albeit smaller, revenue stream of £4.3/MWh, although the amount received by the generator is subject to a supplier margin and is typically lower than this (Carbon Trust, 2006).

6.3.3 European Union Emissions Trading Scheme

The European Union Emissions Trading Scheme (EU-ETS) also provides a source of income whereby the use of biomass can count as an emissions saving for installations taking part in the scheme. The value of the carbon savings varies with the emissions cap and level of compliance, but will improve the cost-effectiveness of measures such as switching to biomass heating in industrial units or co-firing in fossil fuel plants (Rosillo-Calle and Perry, 2006).

6.3.4 Renewable Transport Fuel Obligation

The Renewable Transport Fuel Obligation (RTFO) is due to commence in April 2008,and will require suppliers of transport fuels to ensure that a certain proportion is derived from renewable sources such as biofuels. The level of the RTFO will reach 5% by volume by 2010, with the obligation levels in the years 2008/09 and 2009/10 set at 2.5% and 3.75% respectively (Department for Transport, 2007).

It is suggested that the targets will be met both by imports and a proportion of domestically grown wheat and oilseed rape (Defra, 2007a). If more efficient second generation biofuels derived from woody crops become available by 2020, as is expected by Defra (2007a), this could provide a stimulus for SRC Willow and Miscanthus production.

6.4 Current support for farmers growing dedicated energy crops

A number of grants have been available to farmers throughout the UK for the establishment of SRC Willow and Miscanthus with an energy end use in mind.

In England, the Energy Crops Scheme (ECS) under the 2000-2006 England Rural Development Programme (ERDP) offered £1,000/ha for SRC Willow and £920/ha for Miscanthus. This scheme closed to applicants in the summer of 2006, but a new ECS, offering establishment grants only, will be available under the Rural Development Programme for England (RDPE) 2007-2013. This has now opened for applications although grants are not currently available as the European Commission has yet to approve the RDPE (Natural England, 2007).

In Scotland, SRC Willow has been eligible for payments of £1,000/ha under the Scottish Forestry Grants Scheme. Applications for this scheme closed in December 2006. The level of funding and other details of the new Scottish Forestry Grant Scheme remain dependent on the outcome of the UK's discussions with Brussels over the Rural Development Programme (SAC, 2007).

In Wales an establishment grant for SRC Willow has been available to landowners through the Forestry Commission administered Woodland Grant Scheme, but at only

£600/ha, the grants levels are considerably lower than those available elsewhere. This scheme closed to new applicants in 2006, and no more establishment grants are available for SRC at present (Wales Biomass Centre, 2007).

In Northern Ireland, a 3 year Challenge Fund was established for SRC Willow in 2004. The average rate of assistance is £1,920/ha. The Fund has now closed to new applicants, but a successor programme of support for the continued development of SRC Willow is being sought (DARDNI, 2007).

In addition, since 2004 payments to landowners of up to €45/ha (depending on the uptake of the scheme across the EU) have been offered through the CAP under the Energy Crop Aid Scheme for energy crops (including conventional crops such as wheat and oilseed) that are not grown on set-aside, which have an end-user contract, and which provide a security deposit of €60/ha (RPA, 2007).

7.0 Focus group methodology

Against this background of farmer uncertainty, and as the first stage in a two part Theory of Planned Behaviour (TPB) study (Ajzen, 1991), this study considered the range of potential attitudes using a focus group approach. Focus groups are distinguished from other methods of group interviewing, such as 'brainstorming' or Delphi groups, by the explicit use of the group interaction to produce data and insights that would be less accessible without the interaction found in a group (Morgan, 1988). According to Morgan (1988) ‘focus groups are useful when it comes to investigating *what* participants think but they excel at uncovering *why* participants think as they do’

Focus groups have previously been used for TPB studies (Beedell & Rehman, 2000; Garforth et al., 2004), as they have the advantage of enabling data from a group of people to be gathered more quickly than through individual interviews, and they also permit the researcher to immediately follow-up participant statements in order to clarify responses.

However, there is also the risk that some participants may dominate proceedings, leading more reserved members to hold back.. It must also be borne in mind that the small number of participants mean that findings can't necessarily be generalised to wider populations. It is for this reason, as in this case, that focus groups are often used as a preliminary stage in a larger research program that includes a more representative survey of the population (Walker 1985).

Three groups, held in Thame (Oxfordshire), Bawtry (Nottinghamshire), and Scotlandwell (Fife), took place between November 2006 and January 2007. The locations were chosen for proximity to existing or proposed co-firing or dedicated biomass power plants. Participants were sought through a number of channels (producer groups, Farming and Wildlife Advisory Group (FWAG), National Farmers' Union of England and Wales (NFU) and SAC advisory service) with the intention being to get a broad mix of existing and potential growers of Miscanthus and SRC Willow.

An independent consultant facilitated the discussions, working through a series of broad open-ended questions intended to elicit information on the factors which influence the uptake of dedicated energy crops by farmers. The focus groups typically continued for between 90 and 120 minutes. The discussions were recorded and the output analysed by two researchers, grouping responses into the key themes reported below.

8.0 Findings from focus groups

31 people attended the focus groups including 28 farmers, two producer group representatives, and a power company consultant. 16 farmers had had experience of growing SRC Willow with over half of these attending the Bawtry meeting. Several of these growers originally had contracts with the failed Arbre scheme that was to supply the Eggborough power station in 2000. But the company behind that project

folded in 2002, making 40 people redundant and leaving farmers with acres of half-grown coppicing plantations on their hands.

In total only two farmers had experience of growing Miscanthus, and thus the discussions were more focused on SRC Willow. The area of land in energy crop production on these farms ranged from approximately 5 hectares to 250 hectares, with a median area of 15 hectares. Four farmers had more than 25 hectares in energy crop production, and of these two had an area greater than 100 hectares.

8.1 Motivation to grow energy crops

There was broad consensus that the principle factor affecting a farmer's decision to grow energy crops or not was the perception of potential financial returns. In this respect the contracts available to growers under the original Arbre scheme were said to have been relatively attractive.

Another factor related to personal or ideological beliefs about climate change and fossil fuel dependency. Many of the farmers thought that growing energy crops was fundamentally a 'good' thing, whilst at the same time it was widely thought that such concerns would be a stronger driver in energy crop production in the future.

However, current uncertainty about the financial viability of energy crops appears likely to limit uptake in the short-term despite many farmers being supportive of the underlying principles. A widespread belief was that returns would improve over time, as the government is forced to increase incentives for growing energy crops as part of its programme to tackle climate change. Indeed many of the farmers growing energy crops appear to have speculated that by getting involved at an early stage they will be well placed to benefit later on.

A further factor mentioned by older farmers was the desire to maintain farm production while scaling back daily involvement. In this respect contracting out the entire energy crop production process was seen as attractive.

8.2 Perceptions of financial return

The prices currently paid for energy crops are felt to be low. A key point is the comparison of returns with those from alternative crops or land uses. With wheat having risen dramatically (from £60/t in early 2006 to around £90/t in the second half of the year), the returns available look even less appealing. Within the groups there was much speculation (and some excitement) as to how high the wheat price might go. In this context it was maintained that farmers were very unlikely to sign long-term contracts for willow at the prices currently on offer. Wheat prices are higher still in 2007, with London's November wheat futures closing recently at over £140/t (Farmers Weekly, 2007).

The majority of farmers felt that it was difficult to calculate the returns from energy crops due to uncertainty over costs, potential yields and prices. In comparison farmers were very aware of returns from conventional crops and at what prices and yields they would be profitable. The lack of a mature, fully developed market with clear prices was part of the problem, with a perceived lack of transparency. At present, farmers feel they have little choice but to sell to the power stations for co-firing, where they believe they will always receive the lowest price as the power stations act as 'middle men' in the supply of energy to consumers.

The preferred situation (thought to be the most profitable) for the farmers would be to 'supply kilowatts of heat rather than kilograms of wood' to local schools and hospitals, thus capturing more value through the development of a vertically integrated business. This market is currently very underdeveloped in the UK and reliant on investment in biomass boilers and combined heat and power (CHP) plants. It is interesting to note that this market has perhaps the greatest potential in terms of cost-effective GHG savings. Nevertheless, there was acknowledgement that powers stations had a role to play in developing a market for energy crops.

8.3 Grant support

Very few farmers said they would consider growing energy crops without theestablishment grant, due to the high upfront capital costs and uncertainties over resulting net income. Indeed it was thought that net income would almost certainly be negative at current market prices without grant support. New applications to the English Energy Crop Scheme have been suspended since July 2006 with farmers uncertain as to when these grants will reappear, and expecting grant levels to be lower than previously available. It was felt these issues send poor signals to potential growers, particularly as establishment costs are unlikely to fall significantly in the near future.

The payments of up to €45/ha (on non set-aside) under the EU Energy Crop Aid Scheme did not seem to be an important factor in encouraging uptake, as payments are low in comparison to establishment costs. In principle, however, the additional financial support was welcome. Anecdotal evidence suggests that the administrative requirements for claiming the Energy Crop Aid can be frustrating for farmers due to interaction of claims made under the Single Payment Scheme and the requirement for the processor to lodge a €60/ha deposit.

An important aspect of energy crop production is that producers have high establishment costs yet no income until the first harvest after 4 years. One suggestion made at the discussion groups was that grant monies could be targeted at this period to resolve cash flow problems which may otherwise limit crop uptake.

8.4 Contracts with power stations

There was recognition that with the nature of the cropping cycle, farmers and end-users would continue to rely on contracts, particularly with limited alternative markets for dedicated energy crops (SRC in particular, as Miscanthus has alternative uses e.g. for animal bedding). However, farmers were sceptical that prices offered by power stations would be sufficient to encourage significant uptake. Many believed energy crop prices were calculated when wheat was at £60 per tonne and had failed to rise sufficiently since then. Some felt contracts allowed for lower prices to be paid than they had been led to believe. There was also concern about a farmer's ability to enforce contracts if the end-user decided they didn't want the crop or would only pay a lower price. Nevertheless, there was widespread acceptance that co-firing offers a lifeline to energy crop growers and in many cases constitutes the only viable market.

There was a belief that power stations were motivated primarily by renewable energy obligations and did not really want to use SRC to meet these, as it was more expensive than alternative co-firing feedstocks from forestry or imports. It was also felt that power stations were wavering in their commitment to SRC due to potential changes in the RO rules relating to co-firing. This would seem to tally with the expressed opinions of a number of generators who would rather have freedom to co-fire whatever feedstock they choose (Scottish and Southern Energy, 2006; Scottish Power, 2006), and suggests that removing the cap on energy crops could result in demand from co-firers declining significantly.

8.5 Markets

The 'chicken-and-egg' problem facing market development was identified as an important issue. Farmers have few incentives to grow energy crops without the existence of competitive markets, and potential users have little incentive to invest in the technologies necessary to develop these markets if supply is both limited and uncertain. Many farmers felt that the government must play a significant role to stimulate demand through, for example, providing grants to local authorities, hospitals, schools and businesses to install biomass boilers. Equally it was felt that once a 'critical mass' of energy crop growers had been established, this would increase confidence in energy crop supply, thus prompting more widespread development of markets. Growers perceive that without intervention to stimulate this market then it may take a long time for this ‘critical mass’ to be achieved.

There was also broad recognition that producer groups and cooperatives could play a key role in establishing new markets, as end-users are unlikely to deal with individual growers. Local markets for heat and for CHP were thought to have the most potential to be profitable by allowing farmers to deal directly (through co-operatives or producer groups) with the end-users.

Farmers were keen to stress that development of a mature market for energy crops, would be preferable to a culture of 'handouts'. However, it was conceded that, unless or until, higher energy prices make production more competitive than alternative land uses, subsidies (direct or indirect) would be required for energy crop production to become more widespread. Farmers pointed to Sweden, Germany and Austria as places where markets appear to have developed successfully, and felt that policy makers could learn lessons from the experience gained in these countries.

8.6 Producer groups and co-operation

Co-operation between farmers was seen as essential if new and more profitable markets are to be developed. It was noted that, historically, crop production has not resulted in significant levels of co-operation between farmers. Areas where co-operation should bring benefits include the sharing of experiences on establishment, management, harvesting, processing and marketing of the crops, and collective purchasing of required machinery.

The importance of producer groups was acknowledged, but with awareness that they may not be the most impartial sources of information on energy crop production. The main concerns related to information on potential costs and returns and the more problematic aspects of production. In practice, however, producer groups appeared to enjoy good relationships with most producers and as a result this was not a major issue.

8.7 Type of land used to grow energy crops

Energy crops are more likely to be grown on a farm's least productive land, including arable land, set-aside and permanent pasture taken out of dairy production or currently in grass lets. This reflects the speculative nature of much energy crop production. Several more experienced growers stressed the direct relationship between yields and land productivity, although crop management was also important. Some arable farmers expressed interest in growing energy crop on permanent set-aside land to generate additional income. However, this land tends to be the least productive of a farm's arable land with low yield expectations. Recent European Commission proposals mean set-aside is likely to be suspended in the UK in 2008, with much speculation that it will be scrapped, at least in its current form. These developments will clearly have an effect on the potential for future uptake of energy crops on set-aside.

For most growers, energy crops are a diversification rather than a primary farm enterprise. A small number of farmers had put most or all of their land into energy crop production, which had enabled them to retire or focus on other activities such as contracting. At the moment farmers appear reluctant to use their most productive land for energy crops, but it was stressed that this was linked to the perception of their poor profitability. In principle, many farmers may be willing to consider growing energy crops on more productive land, providing that agronomic conditions are suitable and they have confidence that energy crop production will be competitive in the long-term. Essentially if returns from energy crop production were to be equal to or better than alternative uses, there appears no reason why uptake of energy crop production on all suitable types of land would not increase. However this seems unlikely in the short term, and one can speculate about the longer term opportunity costs of energy crop land uses, given rapidly increasing food demand from China and India.

The perceived negative impact of SRC roots on field drainage can be an important factor in the decision whether or not to grow energy crops. It was interesting that these concerns tended to come from potential growers rather than experienced ones;

the latter group suggesting that careful site selection could prevent this from becoming a serious issue. Furthermore, it is unclear to what extent SRC damages field drainage above and beyond natural deterioration. Nonetheless, at least one producer group advises growers not to grow SRC where there are shallow drains (Thames Valley Bioenergy Coppice, 2007).

The uncertain cost of returning land to alternative production was also a concern expressed by a number of farmers. Some existing growers suggested that it would not be too expensive or difficult; although no-one had direct experience.

8.8 Farm business impacts

Most farmers said they would need to hire contractors for SRC establishment and harvesting due to the expense of purchasing specialist equipment. For Miscanthus it was felt that existing farm equipment might be suitable. Some already make extensive use of contractors in other aspects of their businesses, and therefore using energy crop contractors would have little impact on the farm structure. However, for those farmers who have not traditionally made use of contractors this may be an issue. It was also suggested that growing energy crops could provide an opportunity to reduce fixed costs associated with machinery and labour, thus allowing farmers to engage in other on- or off-farm activities. Some growers have restructured to such an extent that they have become the providers of energy crop contracting services to other growers.

8.9 UK farming sector impacts

There was unanimous agreement that the development of energy crops could only be good for the UK farming sector, as long as farmers could make a profit from growing them. It was thought that the impact of taking land out of production from other agricultural commodities would have the effect of pushing up prices in general and thus benefiting UK agriculture. Several farmers reported that their neighbours had expressed interest in growing energy crops if financial viability could be demonstrated.

8.10 Environmental Impacts

Several farmers with experience of growing energy crops felt that SRC offered clear biodiversity benefits, but that these were not widely recognised by environmental groups and government bodies. Farmers were receiving mixed messages both from different organisations and on occasions from different individuals within a single organisation. Most farmers felt further research would be useful to clarify the impact of energy crops on biodiversity so that a more consistent message can be given.

A number of farmers believed that the public were supportive of them growing energy crops, seeing it as a positive way of tackling climate change. Public concerns over the landscape and visual impacts of energy crops were not thought to be significant at present, but opposition may occur if large scale planting were to take place. Several farmers were keen to point out as an example that initial public reaction to oil seed rape had been negative but that public perceptions were no longer hostile.

The potential for willow to provide environmental services such as water purification on floodplains through the uptake of excess nutrients such as nitrogen was identified. Use of sewage sludge on energy crops was cited as having the twin benefits of providing a safe disposal of waste outside the food chain and acting as a source of nutrients for the crop.

8.11 Sources of information and information gaps

A leaflet on short rotation coppice available from Defra (2006b) had been useful in general terms, although several farmers complained that staff at Defra and the Rural Payments Agency hadn't been able to provide any further information. For many farmers, producer groups had been the main information source. Farmers also received information from power companies and agronomist services contracted to these companies. However, none of these sources were considered to be comprehensive.

Established growers said much of their knowledge was from personal experience and sharing information with other farmers through producer groups and co-operatives. Site visits and talking to growers were also mentioned as a good way for farmers to find out about the practicalities of energy crop production. It was stressed that there was a need for information that was clearly independent, objective, and practical.

None of the farmers had obtained information from the NFU, traditional agronomists, farm advisors or the Biomass Energy Centre; recently set up by the Forestry Commission in response to the findings of the Biomass Task Force. It was reported that the Biomass Energy Centre had actually approached a number of the growers and producer groups from the Bawtry focus group in order to obtain information about energy crops.

Several farmers noted a lack of UK (or indeed Scotland) specific information on growing energy crops, and where information could be found it was not comprehensive and quite fragmented. One farmer suggested that a simple crib sheet with step-by-step details of each stage in the production cycle (establishment, management and harvesting of the crop), as well as details of all administrative requirements, would be helpful. A key gap was also identified in relation to marketing and end uses of energy crops, including information on installing biomass boilers both for on-farm and local energy uses.

It was thought that clear, practical information from impartial research organisations, disseminated through the Biomass Energy Centre, had the potential to complement information provided by producer groups.

9.0 Conclusion

While participants express optimism about the future of energy crop production, there are clearly several barriers to widespread adoption. Key among these is financial returns, and the fact that competing activities are much more rewarding - in particular, wheat and oilseed rape, with current high prices partly driven by demand for liquid biofuels. This raises an important policy issue relating to the cost of abating carbon emissions. Using perennial energy crops for heating is typically a very cost-effective use of biomass to reduce carbon emissions, whereas transport biofuels from grain or oilseed is a much more expensive approach (Carbon Trust, 2005; SAC, 2005).

While the forthcoming RTFO will provide a continued incentive to grow wheat and oilseed rape for biofuels, there is no such support mechanism for renewable heat. The focus on renewable electricity, and more latterly transport fuels, to the exclusion of renewable heat is a concern to both the Royal Commission on Environmental Pollution and the Biomass Task Force (RCEP, 2004; Biomass Task Force, 2005). While the RCEP proposed a 'Renewable Heat Obligation', the Biomass Task Force considered this unworkable, favouring instead a grant programme for boilers, subsequently adopted by Defra as Round 3 of the Bio-energy Capital Grants Scheme (Defra, 2007b). As indicated, farmers believe such grants crucial to create a local demand for renewable heat, which they see as the most profitable future outlet for energy crops.

While successful development of local markets should go some way to increasing returns to farmers and providing reassurance that someone will be able to take the crop at a competitive price, at the current time, planting grants and contracts are still required. There is a need to increase farmer confidence in the contracts, be it perhaps through government underwriting or some form of insurance. An early decision on the establishment grant would also be welcome by farmers as it would mean one less uncertainty.

Finally, farmers need trusted information to make decisions, which predominantly come down to financial considerations at an individual farm level. The issue of SRC roots potentially damaging field drains is a good example where the farmer needs to know how likely this is to happen in his case, and if so, how much it would cost to rectify. It seems that the Biomass Energy Centre, although currently still building up knowledge, is in a good position to become the leading authority.

In terms of further research, there is a need to identify energy crop adoption intentions from a much larger range of farmers. Following from the focus groups, a postal survey based on the Theory of Planned Behaviour (Ajzen, 1991) will be issued to establish the likely wider extent of adoption, as well as identifying the relative importance of drivers and barriers highlighted by the groups. This will enable a better understanding of how policy makers could tackle the specific issues that limit the potential of dedicated energy crops in the UK.

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11.0 References

ADAS, 2003. The Mid-Term Evaluation of the England Rural Development Programme (ERDP): Energy Crop Scheme. Available at http://www.defra.gov.uk/erdp/pdfs/midterm/cs_ecs_3.pdf (accessed August 2007)

Ajzen, I., 1991. The theory of planned behaviour, Organizational Behaviour and Human Decision Processes, 50, 179-211.

Ajzen, I. & Fishbein, M., 1980. Attitudes, Personality and Behaviour. Open University Press, Milton Keynes.

Alker, G. R. and Miller, M., 2006. Critique of 'Evaluating the Sustainability of Co-firing in the UK' a recent report published by the Department of Trade and Industry. Available at http://www.berr.gov.uk/files/file36247.pdf (accessed August 2007)

Andersen, R. S., Towers, W. & Smith, P., 2005. Assessing the potential for biomass energy to contribute to Scotland's renewable energy needs. Biomass & Bioenergy 29, 73-82

Beedell, J. & Rehman, T., 2000. Using social-psychology models to understand farmers' conservation behaviour. Journal of Rural Studies 16, 117-127.

Bical, 2006. Biomass Industrial Crops Ltd. (Bical) response to statutory consultation on the Renewables Obligation Order 2007. Available at

http://www.berr.gov.uk/files/file36708.pdf (accessed August 2007)

Biomass Task Force, 2005. Report to Government, October 2005. Available at http://www.defra.gov.uk/farm/crops/industrial/energy/biomass-taskforce/pdf/btf-finalreport.pdf (accessed August 2007)

Campbell Carr, 2003. Analysis of the Effect of Co-firing Biomass with Fossil Fuels on the Renewables Obligation: A report prepared for the British Wind Energy

Association and Friends of the Earth, November 2003. Available at http://www.foe.co.uk/resource/reports/cofiring_renewables_obligation.pdf (accessed August 2007)

Carbon Trust, 2005. Biomass sector review for the Carbon Trust, October 2005. Available at
http://www.carbontrust.co.uk/publications/publicationdetail?productid=CTC512

(accessed July 2007)

Carbon Trust , 2006. Policy frameworks for renewables: Analysis on policy frameworks to drive future investment in near and long-term renewable power in the UK. Available at
http://www.carbontrust.co.uk/Publications/publicationdetail.htm?productid=CTC610
(accessed August 2007)

Charles, M. B., Ryan, R., Ryan, N., & Oloruntoba, R., 2007. Public policy and biofuels: The way forward? Energy Policy 35, 5737-5746

Council of the European Union, 2007. Presidency Conclusions, Brussels European Council, 8/9 March 2007. Available at
http://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/ec/93135.pdf

(accessed July 2007)

Country Land and Business Association , 2006. Draft response to statutory consultation on the Renewables Obligation Order 2007. Available at

http://www.berr.gov.uk/files/file36715.pdf (accessed August 2007)

DARDNI, 2007. Renewable Energy Action Plan, Department of Agriculture and Rural Development Northern Ireland, January 2007. Available at
http://www.dardni.gov.uk/renewable-energy-action-plan-2.pdf (accessed July 2007)

Defra, 2006a. Creating Value from Renewable Materials: A strategy for non-food crops and uses - Two year progress report, Department for Environment, Food and

Rural Affairs, November 2006. Available at http://www.defra.gov.uk/farm/crops/industrial/pdf/nfc-progress-0611.pdf (accessed July 2007)

Defra, 2006b. Best Practice Guidelines For Applicants to Defra's Energy Crops Scheme: Growing Short Rotation Coppice. Available at http://www.defra.gov.uk/erdp/pdfs/schemes/energy/short-rotation-coppice.pdf (accessed October 2006)

Defra, 2007a. UK Biomass Strategy, Department for Environment, Food and Rural Affairs, May 2007

Defra, 2007b. Bio-energy Capital Grants Scheme, Defra website. Available at http://www.defra.gov.uk/farm/crops/industrial/energy/capital-grants.htm (accessed August 2007).

Department for Transport, 2007. Consultation on the Draft Renewable Transport Fuel Obligations Order 2007, February 2007. Available at http://www.dft.gov.uk/consultations/closed/draftrtfo/rtfo (accessed July 2007)

DTI, 2003a. The Renewables Obligation (Amendment) Order 2003 Statutory Consultation. Department of Trade and Industry. Available at http://www.berr.gov.uk/files/file22098.pdf (accessed August 2007)

DTI, 2003b. Renewables Innovation Review, Department of Trade and Industry. Available at http://www.dti.gov.uk/files/file22017.pdf (accessed July 2007)

DTI, 2006a. Terms of reference for a review of co-firing, Department of Trade and Industry, March 2006. Available at http://www.berr.gov.uk/files/file27963.pdf (accessed August 2007)

DTI, 2006b. Renewable Energy: Reform of the Renewables Obligation and Statutory Consultation on the Renewables Obligation Order 2007 - An Energy review Consultation. Department for Trade and Industry, October 2006. Available at http://www.berr.gov.uk/files/file34470.pdf (accessed August 2007)

DTI, 2007a. Renewable Energy: Reform of the Renewables Obligation, Department for Trade and Industry, May 2007. Available at http://www.berr.gov.uk/files/file39497.pdf (accessed July 2007)

DTI, 2007b. Impact of banding the Renewables Obligation - Costs of electricity production. Report by Ernst & Young to the Department for Trade and Industry, April 2007. Available at http://www.berr.gov.uk/files/file39038.pdf (accessed August 2007)

Ericsson, K. & Nilsson, L., 2006. Assessment of the potential biomass supply in Europe using a resource-focused approach. Biomass & Bioenergy, 30, 1-15

European Commission, 2007. Cereals: Council approves zero set-aside rate for autumn 2007 and spring 2008 sowings. Available at http://europa.eu/rapid/pressReleasesAction.do?reference=IP/07/1402 (accessed September 2007)

FAO, 2007. Crop Prospects and Food Situation, No. 5, October 2007. Food and Agriculture Organisation of the United Nations, Rome. Available at ftp://ftp.fao.org/docrep/fao/010/ah873e/ah873e00.pdf (accessed November 2007)

Farmers Weekly, 2007. Farmers Weekly, 10th August 2007

Foxon, T.J., Gross, R., Chase, A., Howes, J., Arnall, A. & Anderson, D., 2005. UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures. Energy Policy 33 (16) 2123-2137

Garforth, C., Rehman, T., McKemey, K., Tranter, R.B., Cooke, R.J., Yates, C.M., Park, J.R., and Doward, P.T., 2004. Improving the design of knowledge transfer strategies by understanding farmer attitudes and behaviour. Journal of Farm Management 12, 17-32.

Ilex Energy Consulting, 2003. An assessment of changes to the Renewables Obligation rules relating to co-firing: A report to DTI, August 2003. Available at http://www.berr.gov.uk/files/file21086.pdf (accessed August 2007)

IPA Consulting, 2006. The Economics of Co-Firing, report to Department of Trade and Industry, July 2006. Available at http://www.berr.gov.uk/files/file34449.pdf (accessed August 2007)

Jacobsson, S. & Bergek, A., 2004. Transforming the energy sector: the evolution of technological systems in renewable energy technology. Industrial and Corporate Change 13 (5), 815-849

Kemp, R., Schot, J., & Hoogma, R., 1998. Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. Technology Analysis & Strategic Management 10 (2), 175-195

Lords Hansard, 2007. 15 Mar 2007 : Column GC59. Available at http://www.publications.parliament.uk/pa/ld200607/ldhansrd/text/70315-gc0002.htm (accessed August 2007)

Mattison, E. H. A. & Norris, K., 2007. Intentions of UK Farmers toward Biofuel Crop Production: Implications for Policy Targets and Land Use Change. Environmental Science & Technology, Vol 41, 16, 5589-5594

Meijer, I. S. M., Hekkert, M. P. & Koppenjan, J. F. M., 2007. The influence of perceived uncertainty on entrepreneurial action in emerging renewable energy technology; biomass gasification projects in the Netherlands. Energy Policy 35, 5836-5854

Morgan L. D., 1988. Focus groups as qualitative research, Sage Publications, Newbury Park, CA.

Natural England, 2007. Energy Crops Scheme page on Natural England website. Available at http://www.naturalengland.org.uk/planning/grants-funding/energy-crops/default.htm (accessed October 2007)

NFPA, 2007. ROC Auction Prices page on Non Fossil Purchasing Agency website http://www.nfpa.co.uk (accessed August 2007)

NFU, 2006. Statutory Consultation on the Renewables Obligation Order 2007 - Response from the National Farmers' Union of England and Wales. Available at http://www.berr.gov.uk/files/file36752.pdf (accessed August 2007)

OFGEM, 2007. Renewables Obligation: Fuel Measurement and Sampling Guidance, March 2007.

Pöyry Energy Consulting, 2006. Creating ski slopes from cliff edges: removing volume risk from the renewables obligation, May 2006. Available at http://www.ilexenergy.com/pages/157SkiSlopesFromCliffEdges_v3_0.doc

(accessed August 2007)

Raven, R. P. J. M., 2005. Strategic niche management for biomass. Thesis, Eindhoven University of Technology, Eindhoven.

RCEP, 2000. Energy - The Changing Climate: The 22nd Report by the Royal Commission on Environmental Pollution, London.

RCEP, 2004. Biomass as a Renewable Energy Source: A Limited Report by the Royal Commission on Environmental Pollution, London.

RELU, 2009. Policy and Practice Note No. 9, Assessing the social, environmental and economic impacts of increasing rural land use under energy crops, Rural Economy and Land Use Programme, September 2009. Available at http://www.relu.ac.uk/news/policy%20and%20practice%20notes/Karp/Karp.pdf

(accessed November 2009).

Rosenqvist, H. & Dawson, M., 2005. Economics of willow growing in Northern Ireland. Biomass & Bioenergy 28, 7-14.

Rosillo-Calle, F. and Perry, M., 2006. International Energy Agency (IEA) Bioenergy Task 40 - Sustainable International BioEnergy Trade: Securing supply and demand. Country Report for United Kingdom. Imperial College of Science, Technology and Medicine, London.

RPA, 2007. Energy Aid Payments Scheme, Rural Payments Agency website. Available at http://www.rpa.gov.uk (accessed August 2007).

SAC, 2005. Farm level economic impacts of energy crop production: Final report to Defra, August 2005. Available at:

http://www.defra.gov.uk/science/Project_Data/DocumentLibrary/NF0431/NF0431_4015_FRA.doc (accessed July 2007)

SAC, 2007. Commercial viability of alternative non food crops and biomass on Scottish Farms - a special study supported under SEERAD Advisory Activity 211, March 2007. Available at http://www.sac.ac.uk/mainrep/pdfs/nonfoodbiomass.pdf

(accessed July 2007)

Sagar, A. D. & van der Zwaan, B., 2006. Technological innovation in the energy sector : R&D, deployment , and learning-by-doing. Energy Policy 34, 2601-2608

Scottish and Southern Energy, 2006. Response to Statutory Consultation on the Renewables Obligation Order 2007. Available at
http://www.berr.gov.uk/files/file36743.pdf (accessed August 2007)

Scottish Power, 2006. Response to the Statutory Consultation on the Renewables Obligation order 2007. Available at http://www.berr.gov.uk/files/file36745.pdf accessed August 2007.

Skytte, K., Meibom, P., Capral Henriksen, T., 2006. Electricity from biomass in the European Union - with or without biomass import? Biomass & Bioenergy, 30, 385-392

Strawson, J., 2005. Energy Crops and the Market for Biomass in the UK. Nuffield Farming Scholarships Trust, January 2005.

Styles, D. & Jones, M. B., 2007. Current and future financial competitiveness of electricity and heat from energy crops: A case study from Ireland. Energy Policy 35, 4355-4367

Thames Valley Bioenergy Coppice, 2007. Green energy from your land: a fair deal from energy crops in the Thames Valley. Available at http://www.tvbioenergy-coppice.co.uk/pdf/a-fair-deal.pdf (accessed August 2007)

Themba Technology, 2006. Evaluating the Sustainability of Co-firing in the UK (Report for the DTI). Themba Technology Ltd. in collaboration with The Edinburgh Centre for Carbon Management, September 2006.

Unruh, G. C., 2000. Understanding carbon lock-in. Energy Policy (30), 317-325

Upham, P. & Speakman, D., 2007. Stakeholder opinion on constrained 2030 bioenergy scenarios for North West England. Energy Policy 35, 5549-5561

Van der Laak, W. W. M., Raven, R. P. J. M. & Verbong, G. P. J., 2007. Strategic niche management for biofuels: Analysing past experiments for developing new biofuel policies. Energy Policy 35, 3213-3225

Wales Biomass Centre, 2007. Costs, Markets and Grants for Energy Crops, Wales Biomass Centre website. Available at http://www.walesbiomass.org/bio-economics.htm (accessed August 2007)

Walker, R. L., 1985. Applied Quantitative Research, Gower,VT.

Welsh Assembly Government, 2007. Personal communication from Vicky Davies, Rural Development Adviser, Technical Services Division, Welsh Assembly Government, Llandrindod Wells.

Thames Valley Bioenergy Centre, 2007. Green energy from woodlands & dedicated from energy crops in the Thames Valley. Available at http://www.tvenergy.org/pdfs/[illegible].pdf (accessed August 2007)

Themba Technology, 2006. Evaluating the Sustainability of Coppicing in the UK. (Report for the DTI). Themba Technology Ltd. in collaboration with The Edinburgh Centre for Carbon Management. September 2006.

Unruh, G. C., 2000. Understanding carbon lock-in. Energy Policy 28, 817-830.

Upham, P. & Speakman, D., 2007. Stakeholder opinion on constrained 2030 bioenergy scenarios for North West England. Energy Policy 35, 5549-5561.

Van der Laak, W. W. M., Raven, R. P. J. M. & Verbong, G. P. J., 2007. Strategic niche management for biofuels: Analysing past experiments for developing new biofuel policies. Energy Policy 35, 3213-3225.

Wales Biomass Centre, 2007. Crops, Markets and Grants for Energy Crops. Wales Biomass Centre website. Available at http://www.walesbiomass.co.uk/economics.htm (accessed August 2007)

Walker, R. L., 1985. Applied Qualitative Research. Gower, VT.

Welsh Assembly Government, 2007. Personal communication from Viktor Davies, Rural Development Adviser, Technical Services Division, Welsh Assembly Government, Llandrindod Wells.

Chapter 3: Farmer attitudes and intentions towards the adoption of perennial energy crops in the UK: An application of the Theory of Planned Behaviour

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Abstract

The UK Biomass Strategy suggests that to reach the technical potential of perennial energy crops such as short rotation coppice (SRC) willow and miscanthus by 2020 would require 350,000 hectares of land. This would represent a more than 20-fold increase on the current area of 15,546 hectares. The decisions of individual farmers whether or not to grow these crops are therefore a key potential constraint on supply. A postal survey using the social psychology technique the Theory of Planned Behaviour was used to assess behavioural intentions, attitudes, subjective norms, and perceived behavioural control towards the adoption of perennial energy crops. Results suggest that uptake will be minimal unless a number of barriers to adoption are overcome. These include the perceived lack of security and stability of income from contracts, disruption to cashflow, and reduction in the flexibility of the farm business.

12.0 Introduction

The twin concerns of climate change and energy security have increased attention on renewable energy. In the UK, these factors have combined with an agricultural reform process that has highlighted the need for farmers to diversify away from traditionally supported arable and livestock products. Accordingly, the UK Government has in recent years demonstrated an increasing enthusiasm for the use of biomass as a source of electricity, heat and transport fuel. The UK Biomass Strategy states the Government's intention to bring about a major expansion in both the supply and use of biomass in the UK, indicating that biomass will have a central role to play in meeting the EU target of 20% of renewable energy by 2020 (Defra, 2007).

While the UK Biomass Strategy proposes an increase in the use of biomass for heat, electricity and biofuels, beyond acknowledging the 10% minimum share of biofuels target for 2020 (Council of the European Union, 2007) it does not include specific targets for particular feedstocks or end uses. It does, however, outline what the UK Government considers to be the potential UK supply of biomass feedstocks up to 2020. These feedstocks include forestry, wood waste, conventional agricultural crops such as wheat and oilseed rape, straw, perennial energy crops such as short rotation coppice (SRC) willow and miscanthus, and agricultural waste (RCEP, 2004; Defra, 2007).

To increase available biomass, Defra favours obtaining an additional 1 million dry tonnes of wood per annum from woodland and wood waste, more use of manures and slurries, and a substantial growth in uptake of perennial energy crops (Defra, 2007). Of these sources, it is the anticipated change in levels of perennial energy crops that is most dramatic. The technical potential of energy crops is estimated to be 17.2 TWh (1.48 Mtoe), while current availability is 0.07 - 0.09 Mtoe (Defra, 2007). Such an increase would represent an almost 20-fold increase in the level of supply, albeit from a low level.

To reach the technical potential of perennial energy crops by 2020 would require 350,000 hectares (ha) of land, which is roughly 6.5% of UK arable and set-aside land, assuming an average annual yield of 9 odt/ha (Defra, 2007). The Renewables Innovation Review suggests this is a realistic area once a number of constraints, including competition from other markets are taken into account (DTI, 2003).

The key feature of this, and other estimates of future perennial energy crops supply (RCEP, 2004; Carbon Trust, 2005) is the assumption about farmer behaviour. It is taken for granted that farmers will choose to grow perennial energy crops up to the level of the constraints that they identify. However, this assumption does not seem to be supported by experience to date.

Defra's Energy Crops Scheme, which provides establishment grants for SRC willow and miscanthus, along with support for developing SRC producer groups, had a number of objectives for the first period of the England Rural Development Programme (ERDP) (2000-2006). These included the planting, by 2006, of 16,700 ha of SRC and 5000 ha of miscanthus in England (ADAS, 2003). When the scheme closed to applications, in July 2006, only 1180 ha of SRC and 3356 ha of miscanthus had been planted (Defra, 2006a), representing 20% of the target level. This does, however, mark an improvement over the uptake by the half-way point in 2003, where only 2% of the SRC target and 3% of the miscanthus target had been planted (Defra, 2006a).

More recently there has been an increase in interest in the payments, with applications for planting in 2007 due to take the area of miscanthus to 12,627 ha, and SRC to 2600 ha in England (Defra, 2006a).

In Scotland the area planted or approved for planting up until the end of 2006 is 300 ha. Current applications for planting in 2007 and 2008 amount to around 600 ha (SAC, 2007). In Northern Ireland, 400 ha of SRC have been planted or approved for planting to date, and a further 410 ha have been approved for the 2007 planting year, (DARDNI, 2007), while in Wales there is currently 40ha of SRC and 72 ha of miscanthus (WAG, 2007). The current total area of energy crops in the UK is 15,546 ha for SRC willow and miscanthus combined (Defra, 2007).

This paper adds to a growing literature on perennial energy crops and the development of biomass energy in the UK, Europe and beyond (Rosenqvist & Dawson, 2005; Skytte et al., 2006; Charles et al., 2007). While there has been much focus on techno-economic aspects and theoretical supply chain potential (Andersen et al., 2005; Ericsson & Nilsson, 2005; Styles & Jones, 2007), broad stakeholder opinion (Upham & Speakman, 2007) and wider public policy implications (Charles et al., 2007), relatively little is known about how individual farmers will respond to the opportunities presented by these relatively novel crops. Strawson (2005), writing from the perspective of a farmer with land already committed to SRC willow, and at a time when returns from alternative activities were much lower than at present, offers a relatively upbeat assessment of the potential attractiveness of the crop. However, in the context of a significant and ongoing global rise in the price of agricultural commodities such as wheat (FAO, 2007) a changing agricultural policy landscape in the EU (European Commission, 2007) and a UK renewable energy support mechanism that is under review (DTI, 2007), it is important to gain an up-to-date understanding of farmers' attitudes and behavioural intentions towards the adoption of perennial energy crops.

This paper will show that for perennial energy crop feedstocks such as SRC willow and miscanthus, the likely level of supply will be considerably below the theoretical potential unless a number of barriers to their adoption by farmers are overcome. The paper is structured as follows. The next section outlines the framework for investigating the behavioural intentions of UK farmers towards the adoption of perennial energy crops, followed by a description of the survey technique. The results are then presented, with the subsequent discussion looking at the implications of the findings for policy makers.

13.0 Theoretical approach

The Theory of Reasoned Action (TORA) (Ajzen & Fishbein, 1980) and its extension the Theory of Planned Behaviour (TPB) (Ajzen, 1991) provide the conceptual framework for investigating the attitudes and intentions of farmers towards the adoption of perennial energy crops. Both the TORA and the TPB have been widely used in agricultural research to understand barriers and drivers to the adoption of new technologies and practices (Garforth et al., 2004; Beedell & Rehman, 2000; Defra, 2006b) and to estimate the likely scale of adoption of particular activities (Mattison & Norris, 2007).

According to the TORA, the intention to adopt a particular behaviour is a function of attitudes towards the behaviour and the subjective norm, that is the extent to which one is influenced by the views of other people regarding the behaviour (Ajzen & Fishbein, 1980).

Attitudes are a product of the extent to which one expects the behaviour to result in specific outcomes (outcome beliefs) and the importance of those outcomes (outcome evaluations). The subjective norm is a function of the perceived support of salient referents (people to whom respondents might turn for advice) towards the behaviour (subjective beliefs) and the motivation to comply with those beliefs. The TORA claims that the intention to perform a particular behaviour is a reliable indicator of actual future behaviour if the expressed attitude towards this behaviour and/or the perceived social pressure to do so correlate closely with the stated intent. A comparison of the strength of correlation of the attitude and subjective norm with the stated intent towards the adoption of SRC willow or miscanthus indicates which of the two components has greater influence on the farmers' decision relating to the adoption of these crops (Ajzen & Fishbein, 1980).

Theoretical developments in social psychology led to the Theory of Planned Behaviour (see Figure 3), an extension of the TORA that incorporates 'perceived behavioural control' as a measure of the extent to which people believe they are able to control the outcome (Ajzen, 1991). This followed studies suggesting that TORA performed poorly where the perceived efficacy of achieving the expected result was low - in which case the behaviour would not be attempted regardless of the strength of the attitudinal and social influences (Burton, 2004).

Perceived behavioural control is an individual's assessment of their own ability (control belief) to perform a particular behaviour and their capability (power of control). The TPB states that perceived behavioural control can also predict behavioural intent. The contribution of perceived behavioural control is assessed by comparing the strength of its correlation with intent with that of the other two causal components (Ajzen, 1991).

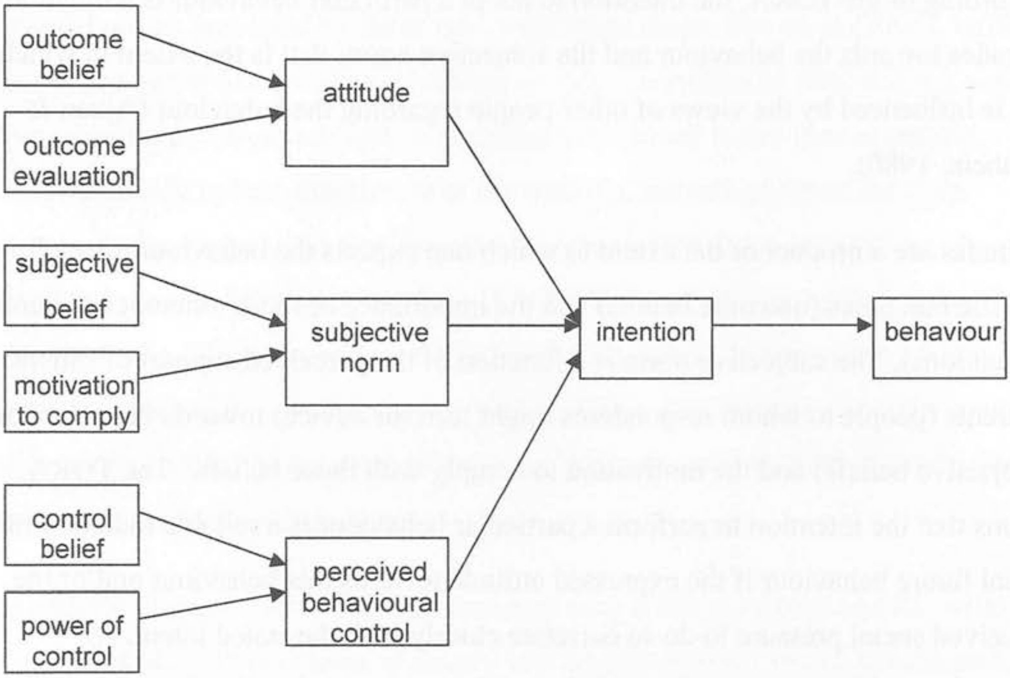

Figure 3: Theory of Planned Behaviour (Ajzen, 1991)

Of central importance within a TPB study is the principle of compatibility, that is "relations between attitudes and behaviours are maximally strong to the extent that their action, target, context, and time elements are assessed at the same level of generality or specificity" (Eagly & Chaiken, 1993). In this study the TPB is applied to predicting farmers' behaviour towards the adoption of perennial energy crops over the next five years.

13.1 Theory of Planned Behaviour study

The research comprised of a two stage interdependent data gathering process. Initially sets of outcome beliefs and salient referents were identified through focus group discussions with farmers in three different areas of the UK (Sherrington et al., 2008). These took place in Thame (Oxfordshire), Bawtry (Nottinghamshire), and Scotlandwell (Fife), between November 2006 and January 2007. The locations were chosen for proximity to existing or proposed co-firing or dedicated biomass power plants, and attracted a mix both of farmers who had experience of growing perennial energy crops and those with no such experience.

The second stage involved using the identified outcome beliefs and salient referents in a structured questionnaire. A copy of the questionnaire is provided at Appendix A.1.0. Following a pilot survey, questionnaires were sent to 1500 farmers in three areas where SRC willow and miscanthus had already been planted under Defra's Energy Crops Scheme in England, and that were within 25 miles of either a co-firing or dedicated biomass power plant. It was decided that this would be preferable to a survey covering the whole of the UK, as in some areas there has been no development of perennial energy crops, co-firing or dedicated biomass power plant. By focusing on areas where there is an existing source of demand, it was considered that the questionnaires would be of more relevance to farmers. Within these areas, farmers were selected at random from a business directory. In all, 150 usable responses were received - a response rate of 10%.

This response rate was disappointing, but within the time constraints of the project it was not possible to attempt any further persuasion of those who had not already responded. While the sample size did allow for the determination of some statistically significant differences between categories, these turned out to be less relevant in policy terms than some of the key findings. For these findings of greater policy relevance, the lack of any significant difference between categories served to emphasise the widely held nature of the generally negative perception of perennial energy crops, and the shared views of the barriers to adoption.

A wider question is whether the farmers targeted were representative of the wider farming community. In spatial terms, only three limited regions were selected for reasons outlined above, so it cannot be claimed that there is full geographical representativeness. No analysis has been undertaken of whether, for example, older or more educated farmers, or certain farm types were over- or under-represented. However, the lack of notable policy relevant significant differences between such categories means that no claims are being made in respect of such differences. However, it would be worthwhile in any future surveys establishing the extent to which the respondents are representative of the wider farming community

Farmers were asked to score a response to the questions on a 5 point scale. These responses were numerically coded from -2 to +2 for analysis. Table 3 shows the question structure for each construct.

TPB Construct	Question Structure	Measurement scale
Behavioural intention	Are you intending to plant SRC willow on your farm in the next 5 years?	Certainly not, probably not, unsure, probably, certainly
Stated attitude	Choosing to plant SRC willow on my farm in the next 5 years would be a good decision	Strongly disagree, disagree, unsure, agree, strongly agree
Stated subjective norm	People whose opinions I value think I should plant SRC willow on my farm in the next 5 years	Strongly disagree, disagree, unsure, agree, strongly agree
Outcome evaluation	Do you agree or disagree with the following statements?	Strongly disagree, disagree, unsure, agree, strongly agree
Belief strength	How important are the following to you?	Unimportant, not very important, no opinion, important, very important
Subjective belief	Do you think the following would approve or disapprove of you growing SRC willow on your farm in the next 5 years?	Strongly disapprove, disapprove, unsure, approve, strongly approve
Motivation to comply	Would you follow the advice of the groups below in deciding whether or not to grow SRC willow on your farm in the next 5 years?	Very unlikely, unlikely, unsure, likely, highly likely
Perceived difficulty	How difficult would it be to grow SRC willow on your farm in the next 5 years?	Very difficult, difficult, unsure, easy, very easy
Perceived ability	How confident are you of being able to grow SRC willow on your farm in the next 5 years?	Not at all confident, not very confident, don't know, confident, very confident

Table 3: Question structure for the TPB survey

Farmers were also invited to add their own thoughts in a comments box at the end of the questionnaire.

14.0 Results

14.1 Description of the sample

The description of the sample is divided into three sub-sections, broadly following the format employed by the University of Reading in a TPB study for Defra in 2006 (Defra, 2006b). The sub-sections are farm characteristics, farm operations and farmer traits (Table 4 to Table 6).

Farm parameters	Overall sample (n=150)		
	Number of	Percentage	Mean, sem and median
Farm types	**146**	-	-
Specialist dairy	36	24.7	
Beef and/or sheep	18	12.3	
Pigs and/or poultry	5	3.4	
Mixed arable and livestock	59	40.4	
Specialist cereals	6	4.1	
General cropping (arable)	18	12.3	
Other	4	2.7	
Farmland type	**149**	-	-
All lowland	124	83.2	
Mostly lowland	12	8.1	
Half and half	7	4.7	
Mostly upland	1	0.7	
All upland	5	3.4	
Total farmed area (ha)	**127**		188.3 + 21.73; 112ha
Up to 58ha	32	25.2	
58.1 - 112ha	32	25.2	
112.1 - 230ha	33	26.0	
>230ha	30	23.6	
Tenure	**103**		
Tenanted	20	19.4	
Owned outright	49	47.6	
Part tenanted/part owned	34	33.0	

Table 4: Sample description based on farm characteristics

About 40% of the sample were mixed arable and livestock, followed by specialist dairy (25%), with beef and/or sheep and general cropping (arable) both at 12%. Specialist cereals accounted for just over 4%, and pigs and/or poultry just over 3%. Others (nearly 3%) comprised of a mixture of the main categories along with specialist vegetables. Of the five farmland types, all lowland dominated, with over 80% of the sample falling into this category, followed by mostly lowland (8%) and half and half (just under 5%).

Just over 3% were all upland, with less than 1% mostly upland. The mean farmed area for the whole sample was 188ha, whereas the median area was 112ha.

Table 5 describes the sample based on farm operations. Just over half recorded annual sales of agricultural produce of over £100,000. About a fifth had sales of £50 - 100,000, and a similar proportion had sales of £10 - 50,000. Fewer than 10% of respondents had annual sales of less than £10,000. In terms of the proportional contribution of farming to annual household income, over half indicated that they are fully dependent, with one fifth about 75% dependent on farming. 61% of respondents indicated that their farm has made a moderate profit over the past three years, with 6% recording a significant profit. About 20% broke even, 9% incurred a moderate loss, and 4% a significant loss.

In response to a question about the extent of involvement in businesses run by farmers groups, 48% said they are not at all involved, with 46% involved occasionally. Only 6% are involved at every opportunity. Almost half of respondents said that the farm business carried no debt. Nearly 39% said they were lightly in debt, and over 13% heavily in debt.

Only 14% of respondents had fixed costs below 20%, while 44% had fixed costs from 21-40%. Just over a fifth had fixed costs of over 40%, while a further fifth did not know the proportion of total annual farm costs that were fixed costs. When asked about the proportion of income from environmental schemes, almost three quarters indicated that these represented less than 5% of their income. For 10% of respondents environmental schemes contributed 20% or more of annual farm income.

In response to the question about the proportion of total income accounted for by the Single Farm Payment, 70% said that this represented less than 40% of their income, while for 20% it represented about half of their income. For 10% it represented more than half of their income.

Farm operation parameters	Overall sample	
	Number of	(%)
Annual value of total sales of agricultural produce	**136**	-
Less than £10,000	12	8.8
£10,001 to £50,000	30	22.1
£50,001 to £100,000	25	18.4
Over £100,000	69	50.7
Proportion of annual household income from farming	**142**	-
100%	76	53.5
About 75%	30	21.1
About 50%	13	9.2
About 25%	9	6.3
Below 25%	14	9.9
Over past three years has farm made a profit or a loss?	**142**	-
Significant profit	9	6.3
Moderate profit	86	60.6
Break even	28	19.7
Moderate loss	13	9.2
Significant loss	6	4.2
Extent of involvement in businesses run by farmer groups	**142**	-
Not at all	68	47.9
Occasionally	65	45.8
At every opportunity	9	6.3
Farm business in debt	**139**	-
Not at all	66	47.5
Lightly	54	38.8
Heavily	19	13.7
Proportion of total annual farm costs that are 'fixed' costs	**139**	-
Less than 10%	6	4.3
10 - 20%	13	9.4
21 - 30%	34	24.5
31 - 40%	27	19.4
41 - 50%	13	9.4
Over 50%	17	12.2
Don't know	29	20.9
Proportion of farm income from environmental schemes	**145**	-

Less than 5%	106	73.1
Around 10%	24	16.6
Around 20%	8	5.5
Higher than 20%	7	4.8
Proportion of total income from SFP	**145**	-
Less than 40%	101	69.7
Around half	29	20.0
More than half	15	10.3

Table 5: Sample description based on farm operations

The male and female respondents comprised 95 and 5 percent respectively of the sample (see Table 6). The mean age of respondents was 53 years. Almost half fell between the ages of 41 and 55, with 20% aged between 56 and 65, and 17% aged over 65. Sixteen percent of respondents were under 40.

In terms of the highest level of formal education attained, 23% have university degrees, with 41% having qualifications from technical colleges. The remaining 36% were educated to secondary school level.

In response to the question as to whether they see themselves as early adopters of technology, 40% indicated that they were. A further 40% said they were not early adopters, while the remaining 20% stated that they don't know.

Thirty-five percent of respondents had identified a successor to take over the farm, while just under half had not. The remaining 16% answered that they may have identified a successor.

Farmer traits	Overall sample (n=150)		
	Number of respondents	Percentage (%)	Mean, sem and median values
Gender	**142**	-	
Male	135	95.1	
Female	7	4.9	
Age	**127**	-	52.7 ± 1.0; 52 years
Up to 40 years	20	15.7	
41 - 55 years	60	47.2	
56 - 65 years	25	19.7	
>65 years	22	17.3	
Education status	**140**	-	
Secondary	51	36.4	
Technical College	57	40.7	
University	32	22.9	
Early adopter of technology?	**143**		
Yes	57	39.9	
No	58	40.6	
Don't know	28	19.6	
Have you identified a successor?	**142**		
Yes	50	35.2	
No	69	48.6	
Maybe	23	16.2	

Table 6: Sample description based on farmer traits

Three of the farmers who responded are already growing SRC willow, with areas of 10, 34 and 53 hectares. Nine farmers are already growing miscanthus, with eight indicating the area of the crop. This ranged from 4ha to 60ha, with a mean of 20.6ha and a median of 17.5ha.

14.2 Behavioural intentions

When existing growers were asked whether they planned to plant more SRC willow on their farm, the farmer with 10ha said 'certainly not', the farmer with 53ha said 'probably not', while the farmer with 34ha was unsure. Of those already growing miscanthus, two were 'certainly not' going to plant more, two were 'probably not', and one was unsure. One farmer said he probably would, while two certainly would.

The key questions relating to behavioural intention asked farmers who were not already growing perennial energy crops 'Are you intending to plant SRC willow on your farm in the next 5 years?', and 'Are you intending to plant miscanthus on your farm in the next 5 years?'

The responses are shown in Figure 4. It can be seen that stated intentions towards the adoption of both crops are generally negative, with the means for both lying between 'certainly not' and probably not'. The stated intention towards miscanthus (mean - 1.26) is slightly less negative than the stated intention towards SRC willow (mean - 1.37).

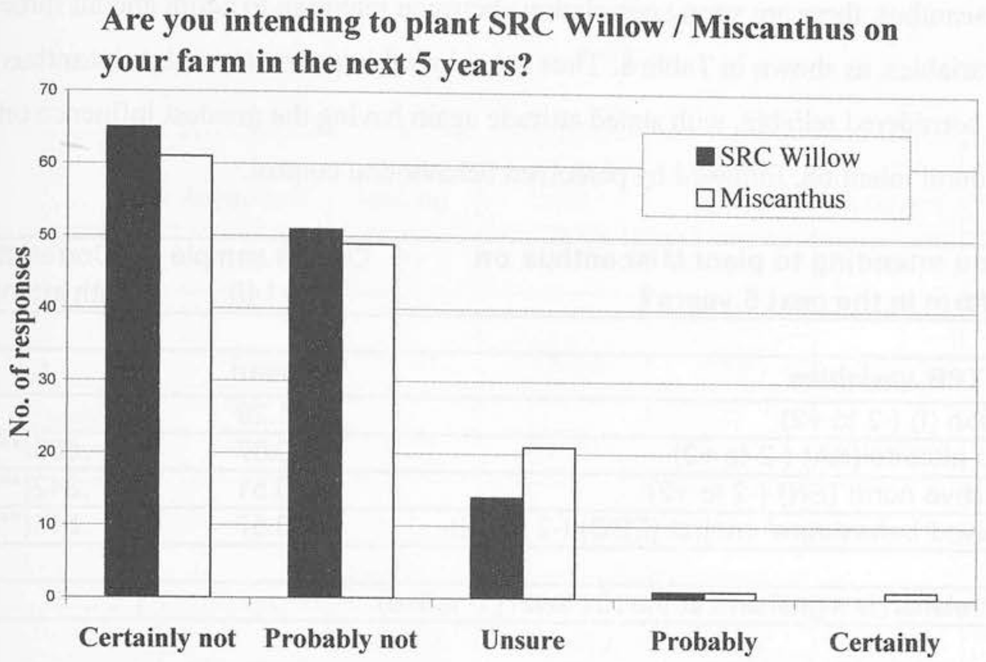

Figure 4: Behavioural intentions towards planting perennial energy crops

According to the TPB, behavioural intention is a reliable predictor of actual behaviour if at least one of the three main variables (attitude, subjective norm, or perceived behavioural control) correlates strongly with the stated intention. Table 7 shows that there is a strong correlation between intention to adopt SRC willow and all three variables. Thus behavioural intention towards SRC willow can be considered reliable, with stated attitude having the greatest influence on behavioural intention.

Are you intending to plant SRC Willow on your farm in the next 5 years?	Overall sample n=149	Correlation with intent (I)
Main TPB variables	Mean	r_s
Intention (I) (-2 to +2)	-1.37	
Stated attitude (SA) (-2 to +2)	-0.77	.586(**)
Subjective norm (SN) (-2 to +2)	-0.64	.440(**)
Perceived behavioural control (PBC) (-2 to +2)	-0.67	.440(**)
** Correlation is significant at the .01 level (1-tailed)		

Table 7: Correlation of main TPB variables with intention to adopt SRC willow

For miscanthus, there are strong correlations between intention to adopt and all three main variables, as shown in Table 8. Thus behavioural intention towards miscanthus can be considered reliable, with stated attitude again having the greatest influence on behavioural intention, followed by perceived behavioural control.

Are you intending to plant Miscanthus on your farm in the next 5 years?	Overall sample n=149	Correlation with intent (I)
Main TPB variables	Mean	r_s
Intention (I) (-2 to +2)	-1.26	
Stated attitude (SA) (-2 to +2)	-0.67	.585(**)
Subjective norm (SN) (-2 to +2)	-0.51	.342(**)
Perceived behavioural control (PBC) (-2 to +2)	-0.57	.511(**)
** Correlation is significant at the .01 level (1- tailed)		

Table 8: Correlation of main TPB variables with intention to adopt miscanthus

A Kruskal-Wallis analysis was undertaken to see if there is any significant difference in behavioural intention by any of the categories of farm characteristics, farm operations and farmer traits (see Table 4, to Table 6). For SRC willow, significant differences existed in just two categories - farmland type and the extent of farm profit or loss. Table 9 shows that for farmland type, using the Mann-Whitney U-test, there is a significant difference in adoption intention between 'all lowland', with a mean score of -1.45 (halfway between probably not and certainly not) and 'all upland', with a mean score of -0.5 (halfway between unsure and probably not).

	All lowland	Mostly lowland	Half and half	Mostly upland	All upland	
n	110	10	7	0	4	
	mean	mean	mean	mean	mean	K-W. Sig
Intention (-2 to +2)	-1.45	-1.20	-1.00	-	-0.50	.026
Mann-Whitney U-test significance values						
	All lowland	Mostly lowland	Half and half	Mostly upland	All upland	
All lowland		ns	ns	-	.010	
Mostly lowland	ns		ns	-	ns	
Half and half	ns	ns		-	ns	
Mostly upland	-	-	-		-	
All upland	.010	ns	ns	-		

Table 9: SRC willow adoption intentions by farmland type

Notwithstanding the small number of 'all upland' farms, in policy terms this does not seem to be immediately helpful as the adoption intention for 'all upland' farms is still negative, even if to a lesser extent than for 'all lowland' farms.

	Significant profit	Mod. profit	Break even	Mod. loss	Significant loss	
n	8	80	22	10	5	
	mean	mean	mean	mean	mean	K-W. Sig
	-1.75	-1.44	-1.00	-1.30	-2	.005
Mann-Whitney U-test significance values						
	Significant profit	Mod. profit	Break even	Mod. loss	Significant loss	
Significant profit	▨	ns	.009	ns	ns	
Moderate profit	ns	▨	.007	ns	.050	
Break even	.009	.007	▨	ns	.004	
Moderate loss	ns	ns	ns	▨	.034	
Significant loss	ns	.050	.004	.034	▨	

Table 10: SRC Willow adoption intentions by extent of profit or loss

Table 10 shows the significant differences in SRC willow adoption intentions between farms that recorded a significant loss (mean -2.00), and those who broke even (mean -1.00), or had a moderate profit (mean -1.44) or loss (mean -1.30). There are also significant differences between those who broke even and those where a moderate or significant profit (mean -1.75) was recorded. However the means of the adoption intentions by extent of profit or loss all fall between 'probably not' and 'certainly not'.

For miscanthus adoption intentions, shown in Table 11, a significant difference exists between those who consider themselves to be early adopters of technology (mean -1.29) and those who responded 'don't know' (mean -0.84). A further significant difference exists between those who do not consider themselves to be early adopters of technology (mean -1.41) and those who responded 'don't know'. However, there is no significant difference between those who responded 'yes' and those who responded 'no', and there are obvious practical difficulties in actually identifying those who don't know whether or not they are early adopters. Moreover, all three mean responses were negative, ranging from just below 'probably not', to nearly half-way between 'probably not' and 'certainly not'.

	Yes	No	Don't know	
n	48	56	25	
	mean	mean	mean	K-W. Sig
Intention (-2 to +2)	-1.29	-1.41	-0.84	.022
Mann-Whitney U test significance values				
	Yes	No	Don't know	
Yes		ns	.037	
No	ns		.006	
Don't know	.037	.006		

Table 11: Miscanthus adoption intentions by whether the farmer considers themselves to be an early adopter of technology

There are also significant differences in miscanthus adoption intentions by the extent of farm profit or loss. Table 12 shows that significant differences exist between those recording a significant loss (mean -2.00) and those who broke even (mean -1.04) or made a moderate profit (mean -1.32) or loss (mean -1.10).

	Significant profit	Mod. profit	Break even	Mod. loss	Significant loss	
n	8	81	23	10	5	
	mean	mean	mean	mean	mean	K-W. Sig
	-1.63	-1.32	-1.04	-1.10	-2	.041
Mann-Whitney U-test significance values						
	Significant profit	Mod. profit	Break even	Mod. loss	Significant loss	
Significant profit		ns	ns	ns	ns	
Moderate profit	ns		ns	ns	.029	
Break even	ns	ns		ns	.010	
Moderate loss	ns	ns	ns		.036	
Significant loss	ns	.029	.010	.036		

Table 12: Miscanthus adoption intentions by extent of profit or loss

Again these are all negative adoption intentions ranging from 'probably not' to 'certainly not'.

14.3 Attitudes

Stated or general attitude towards the adoption of SRC willow was derived from the response to the statement 'Choosing to plant SRC Willow on my farm in the next 5 years would be a good decision'. Possible responses ranged from strongly agree to strongly disagree (See Table 3). The mean value for the stated attitude towards adoption of SRC willow is -0.77 (see Table 7). Stated attitude has the strongest influence on behavioural intention of all three main TPB variables (See Table 7). In order to get a more detailed understanding of attitudes, respondents were asked to indicate their level of agreement/disagreement with a number of specific outcome beliefs that had arisen from the focus groups. They also had to indicate the level of importance attached to these outcomes.

	Belief (-2 to +2)	Value (-2 to +2)	Attitude (-4 to +4)
	Mean	Mean	Mean
SRC Willow will give a high gross margin	-0.45	1.31	-0.62
Growing SRC Willow to contract will give me greater income security	-0.32	1.47	-0.35
Growing SRC Willow fits in with my current cropping plans	-0.89	1.15	-1.11
Growing SRC Willow to contract will give me greater stability of income	-0.43	1.21	-0.43
It is easy to do the paperwork required to grow SRC Willow to contract	-0.08	0.75	-0.17
SRC Willow roots will damage field drains	-0.42	1.05	-0.99
Growing SRC Willow will reduce the flexibility of the farm business	-0.5	1.03	-0.66
Growing SRC Willow is a good way for farmers to help tackle climate change	0.31	0.48	0.36
SRC Willow could be a good source of energy for local or on-farm use	0.3	-0.11	0.31
The likely costs and returns of SRC Willow are easy to calculate	-0.01	1.33	0.02
Growing SRC is a good opportunity to reduce the time spent on farming activities	0.22	0.09	0.09
Growing SRC Willow will disrupt my cashflow	-0.19	1.36	-0.35

Table 13: Outcome beliefs, outcome evaluations and attitudes towards the adoption of SRC willow

Most of the outcome beliefs in Table 13 are negative. For example, there is moderate disagreement (i.e. somewhere between unsure and disagree) that SRC willow will give a high gross margin. The outcome evaluations are mostly positive, indicating for example that getting a high gross margin lies somewhere between important and very important. Multiplying these scores through for each respondent gives a calculated attitude score for each statement. The three most negative attitudes relate to SRC willow not fitting in with current cropping plans, willow roots damaging field drains, and SRC willow reducing the flexibility of the farm business.

Of key importance in establishing the strength of these attitudinal influences on intention to adopt is the correlation with the stated intent. This shows (Table 14) that the most important attitudinal barriers to the adoption of SRC willow are the belief that growing SRC willow to contract will not give greater stability of income, followed by SRC willow not fitting in with current cropping plans. The next most significant are SRC willow roots damaging field drains, the lack of improved income security from SRC willow, reducing the flexibility of the farm business, and disrupting cashflow.

	Attitude (-4 to +4)	Correlation with intent (I)
	Mean	r_s
SRC Willow will give a high gross margin	-0.62	.101
Growing SRC Willow to contract will give me greater income security	-0.35	.240(**)
Growing SRC Willow fits in with my current cropping plans	-1.11	.314(**)
Growing SRC Willow to contract will give me greater stability of income	-0.43	.342(**)
It is easy to do the paperwork required to grow SRC Willow to contract	-0.17	.004
SRC Willow roots will damage field drains	-0.99	.286(**)
Growing SRC Willow will reduce the flexibility of the farm business	-0.66	.220(**)
Growing SRC Willow is a good way for farmers to help tackle climate change	0.36	.058
SRC Willow could be a good source of energy for local or on-farm use	0.31	.067
The likely costs and returns of SRC Willow are easy to calculate	0.02	.020
Growing SRC is a good opportunity to reduce the time spent on farming activities	0.09	.063
Growing SRC Willow will disrupt my cashflow	-0.35	.217(**)
** Correlation is significant at the .01 level (1- tailed)		

Table 14: Correlation between calculated attitudes and stated intention towards SRC willow

Interestingly, gross margin is not significantly correlated with intention to adopt SRC willow. This has important policy implications. It suggests that simply offering more money to farmers to grow SRC willow will not work unless a number of other 'preconditions' such as concerns over stability and security of income from contracts, as outlined above, are addressed.

Stated or general attitude towards the adoption of miscanthus was derived from the response to the statement 'Choosing to plant miscanthus on my farm in the next 5 years would be a good decision'. Possible responses ranged from strongly agree to strongly disagree (See Table 3). The mean value for the stated attitude towards adoption of miscanthus is -0.67 (see Table 8). As with SRC willow, stated attitude has the strongest influence on behavioural intention towards miscanthus of all three main TPB variables (See Table 8). Again in order to get a more detailed understanding of attitudes towards adoption of miscanthus, respondents were asked to indicate their level of agreement/disagreement with a number of specific outcome beliefs that had arisen from the focus groups.

Most of the outcome beliefs (See Table 15) for miscanthus are negative, although farmers are unsure/mildly disagree that they will damage field drains. The outcome evaluations are identical to those previously recorded for SRC willow as these questions were combined in the interest of brevity. Again, multiplying these scores through for each respondent gives a calculated attitude for each statement.

	Belief (-2 to +2)	Attitude (-4 to +4)	Correlation with intent (I)
	Mean	Mean	r_s
Miscanthus will give a high gross margin	-0.35	-0.46	.158(*)
Growing Miscanthus to contract will give me greater income security	-0.12	-0.01	.329(**)
Growing Miscanthus fits in with my current cropping plans	-0.63	-0.8	.423(**)
Growing Miscanthus to contract will give me greater stability of income	-0.25	-0.22	.456(**)
It is easy to do the paperwork required to grow Miscanthus to contract	-0.04	-0.13	.064
Miscanthus roots will damage field drains	0.12	-0.12	.130
Growing Miscanthus will reduce the flexibility of the farm business	-0.25	-0.29	.103
Growing Miscanthus is a good way for farmers to help tackle climate change	0.31	0.39	.150(*)
Miscanthus could be a good source of energy for local or on-farm use	0.29	0.26	.073
The likely costs and returns of Miscanthus are easy to calculate	0.05	0.15	.156(*)
Growing Miscanthus is a good opportunity to reduce the time spent on farming activities	0.2	0.15	.016
Growing Miscanthus will disrupt my cashflow	-0.26	-0.43	.144

** Correlation is significant at the .01 level (1- tailed)

* Correlation is significant at the .05 level (1- tailed)

Table 15: Outcome beliefs, calculated attitudes, and correlation between calculated attitudes and stated intention towards miscanthus.

The three most negative attitudes relate to miscanthus not fitting in with current cropping plans, not having a high gross margin, and disrupting cashflow. Again it is important to establish the strength of these influences on intention to adopt. The final column of Table 13 shows that the most significant attitudinal barriers to adoption for miscanthus are the belief that growing miscanthus to contract will not give greater stability of income, followed by miscanthus not fitting in with current cropping plans, and not increasing income security. Less significant correlations include miscanthus not having a high gross margin.

14.4 Subjective norm

Stated or general subjective norm towards the adoption of SRC willow was derived from the response to the statement 'People whose opinions I value think I should plant SRC willow on my farm in the next five years'. Possible responses ranged from strongly agree to strongly disagree (See Table 3). The mean value for the stated subjective norm towards adoption of SRC willow is -0.64 (see Table 7). Stated subjective norm is strongly correlated with behavioural intention, with an influence on behavioural intention equal to that of perceived behavioural control but less than that of stated attitude (See Table 7).

A key part of any agricultural knowledge transfer strategy is to identify appropriate channels for communicating with farmers about specific new policies or techniques (Garforth et al., 2004). These trusted sources of advice and influence can be identified by using the TPB. A number of salient referents were identified in the focus groups, and respondents to the questionnaire were asked to indicate the extent to which these referents would approve or disapprove of them growing SRC willow on their farms in the next five years (subjective belief). They were also asked how likely it was that they would follow the advice of these referents in relation to the adoption of these perennial energy crops (motivation to comply).

	Subjective belief (-2 to +2)	Motivation to comply (-2 to +2)	Subjective norm (-4 to +4)	Correlation with intent (I)
	Mean	Mean	Mean	r_s
Would the following approve or disapprove of you growing SRC Willow?				
Farmers clubs	-0.04	-0.61	0.19	-.019
Existing SRC growers	0.45	-0.12	0.15	.152
Other farmers	-0.13	-0.16	0.35	-.107
SRC Producer groups	0.63	-0.17	0.07	.168(*)
Power companies	0.7	-0.47	-0.28	.253(**)
Farming press	0.41	-0.37	-0.03	.160(*)
Defra	0.51	-0.47	-0.15	.158(*)
Biomass Energy Centre	0.88	-0.24	-0.11	.200(*)
NFU	0.29	-0.35	0.1	.027
Agronomist	-0.25	0	0.1	.093
Own experience / judgement	-0.32	0.28	-0.03	.112
Family	-0.32	0.01	0.05	-.031
Members of the public	0.28	-0.9	-0.15	.019
** Correlation is significant at the .01 level (1- tailed)				
* Correlation is significant at the .05 level (1- tailed)				

Table 16: Mean subjective belief, motivation to comply, subjective norm for salient referents with regard to the adoption of SRC willow, and correlation of referent subjective norm with intent.

The subjective beliefs listed in Table 16 show that, as might be expected, farmers think that those who would most strongly approve of them growing SRC willow are the Biomass Energy Centre (mean 0.88), power companies (mean 0.70), SRC producer groups (mean 0.63), and Defra (mean 0.51).

Still with a positive mean, but closer to 'unsure' than 'approve', are existing SRC growers (mean 0.45), farming press (mean 0.41), NFU (mean 0.29) and members of the public (mean 0.28). Negative means, moving from 'unsure' towards 'disapprove' were obtained for farmers clubs (mean -0.04), other farmers (mean -0.13), agronomist (mean -0.25), and own experience/judgement and family both with a mean of -0.28.

What is particularly interesting is the motivation to comply with the various salient referents, which tends to be negative, but not strongly. This would support the findings from the focus groups (Sherrington et al., 2008) that farmers are sceptical of certain interests, that there is a need for clear, unbiased information, and that farmers really don't know where to turn for advice on perennial energy crops. Indeed the mean for own experience/judgement (0.28) suggests that farmers do not have confidence in their own judgement on perennial energy crops. The least negative means, following own experience/judgement and family are agronomist (mean 0), existing SRC growers (mean -0.12), other farmers (mean -0.16) and SRC producer groups (mean -0.17). This would suggest that the current practice of farm open days, where prospective adopters view SRC willow being grown and harvested are a relatively effective way of getting information across.

Multiplying through the scores for subjective belief and motivation to comply for each individual we get the referent subjective norm. Looking at the correlation of the referent subjective norms with intent in isolation, one might be forgiven for thinking that power companies are the best channel for extending information to potential growers of SRC willow. However, as we have seen, this strong correlation with intent is in fact due to the negative motivation to comply with a referent who approves of an activity that the majority of respondents do not in fact plan to undertake.

Stated or general subjective norm towards the adoption of miscanthus was derived from the response to the statement 'People whose opinions I value think I should plant miscanthus on my farm in the next five years'. Possible responses ranged from strongly agree to strongly disagree (See Table 3). The mean value for the stated subjective norm towards adoption of miscanthus is -0.51 (see Table 8). Stated subjective norm is strongly correlated with behavioural intention, but with an influence on behavioural intention less than that of both perceived behavioural control and stated attitude (See Table 8).

Respondents to the questionnaire were asked to indicate the extent to which the salient referents would approve or disapprove of them growing miscanthus on their farms in the next five years (subjective belief). Their motivations to comply with these salient referents are identical to those previously recorded for SRC willow as these questions were combined. This followed feedback from the pilot survey where it was identified that the questionnaire was too long.

The subjective beliefs listed in Table 17 show that, again as might be expected, farmers think that those who would most strongly approve of them growing miscanthus are the Biomass Energy Centre (mean 0.78), power companies (mean 0.70), and miscanthus producer groups (mean 0.65).

Still with a positive mean, but closer to 'unsure' than 'approve', are Defra (mean 0.49), existing miscanthus growers (mean 0.43), farming press (mean 0.33), NFU (mean 0.24) members of the public (mean 0.08), and farmers clubs (0.03). Negative means, moving from 'unsure' towards 'disapprove' were obtained for other farmers (mean -0.01), agronomist (mean -0.17), family (mean of -0.21), and own experience/judgement with a mean of -0.22.

These subjective beliefs are very close to those given for SRC willow, and underline the uncertainty as to what farmers believe many referents actually think about the adoption of perennial energy crops.

	Subjective belief (-2 to +2)	Motivation to comply (-2 to +2)	Subjective norm (-4 to +4)	Correlation with intent (I)
	Mean	Mean	Mean	r_s
Would the following approve or disapprove of you growing Miscanthus?				
Farmers clubs	0.03	-0.61	0.16	-.019
Existing Miscanthus growers	0.43	-0.12	0.33	.152
Other farmers	-0.01	-0.16	0.35	-.107
Miscanthus producer groups	0.65	-0.17	0.2	.168(*)
Power companies	0.70	-0.47	-0.17	.253(**)
Farming press	0.33	-0.37	0.02	.160(*)
Defra	0.49	-0.47	-0.08	.158(*)
Biomass Energy Centre	0.78	-0.24	-0.02	.200(*)
NFU	0.24	-0.35	0.14	.027
Agronomist	-0.17	0	0.3	.093
Own experience/judgement	-0.22	0.28	0.08	.112
Family	-0.21	0.01	0.15	-.031
Members of the public	0.08	-0.90	0.02	.019
** Correlation is significant at the .01 level (1- tailed)				
* Correlation is significant at the .05 level (1- tailed)				

Table 17: Mean subjective belief, motivation to comply, subjective norm for salient referents with regard to the adoption of miscanthus, and correlation of referent subjective norm with intent.

Multiplying through the scores for subjective belief and motivation to comply for each individual we get the referent subjective norm. Looking at the correlation of the referent subjective norms with intent in isolation, it again appears that power companies are the best channel for extending information to potential growers of miscanthus. However, once more this strong correlation with intent is in fact due to the negative motivation to comply with a referent who approves of an activity that the majority of respondents do not in fact plan to undertake.

14.5 Perceived behavioural control

Perceived behavioural control in respect of the adoption of SRC willow was obtained from the mean value of responses to two statements relating to difficulty and ability. The first was 'How difficult would it be to grow SRC willow on your farm in the next 5 years?'. Possible responses ranged from very difficult to very easy (See Table 3). The second was 'How confident are you of being able to grow SRC willow on your farm in the next 5 years?'. Possible responses ranged from very confident to not at all confident (See Table 3).

The mean value for perceived behavioural control in respect of the adoption of SRC willow is -0.67 (see Table 7). This correlates strongly with stated intent, and exerts a similar level of influence on intent as stated subjective norm, but less influence on intent than stated attitude (See Table 7).

When the two components of perceived behavioural control in respect of the adoption of SRC willow are viewed independently (See Table 18), farmers see growing SRC willow as moderately difficult (mean -0.38), but when it comes to confidence in their ability to grow it, they are not very confident (mean -0.97). Both ability and difficulty are strongly correlated with behavioural intent, with ability exerting the stronger influence.

Are you intending to plant SRC Willow on your farm in the next 5 years?	Overall sample n=149	Correlation with intent (I)
Main TPB variables	Mean	rs
Intention (I) (-2 to +2)	-1.37	
PBC (-2 to +2)	-0.67	.440(**)
Difficulty	-0.38	.301(**)
Ability	-0.97	.501(**)
** Correlation is significant at the .01 level (1- tailed)		

Table 18: Mean scores for PBC, Difficulty and Ability in respect of the adoption of SRC Willow, and correlation with intent.

These results would appear to support the view from the focus groups that specialist contractors would be needed for SRC establishment and harvesting due to the requirement of specialist equipment (Sherrington et al., 2008).

Perceived behavioural control in respect of the adoption of miscanthus was obtained in the same way - from the mean value of responses to two statements relating to difficulty and ability. The first was 'How difficult would it be to grow miscanthus on your farm in the next 5 years?'. Possible responses ranged from very difficult to very easy (See Table 3). The second was 'How confident are you of being able to grow miscanthus on your farm in the next 5 years?'. Possible responses ranged from very confident to not at all confident (See Table 3).

The mean value for perceived behavioural control in respect of the adoption of miscanthus is -0.57 (see Table 8). This correlates strongly with stated intent, and exerts more influence on intent than stated subjective norm, but slightly less influence on intent than stated attitude (See Table 8).

When the two components of perceived behavioural control in respect of the adoption of miscanthus are viewed independently (See Table 17), farmers see growing miscanthus as moderately difficult (mean -0.35), but when it comes to confidence in their ability to grow it, they are not very confident (mean -0.81). Both ability and difficulty are strongly correlated with behavioural intent, with ability exerting the stronger influence.

Are you intending to plant Miscanthus on your farm in the next 5 years?	Overall sample n=149	Correlation with intent (I)
Main TPB variables	Mean	rs
Intention (I) (-2 to +2)	-1.26	
(PBC) (-2 to +2)	-0.57	.511(**)
Difficulty	-0.35	.387(**)
Ability	-0.81	.578(**)
** Correlation is significant at the .01 level (1- tailed)		

Table 19: Mean scores for PBC, Difficulty and Ability in respect of the adoption of miscanthus, and correlation with intent.

15.0 Discussion

While it is fairly common for farmers not to admit to outside sources of influence in open discussion (Burton, 2004), other postal surveys have elicited a number of positive mean sources of influence (Garforth et al., 2004; Mattison & Norris, 2007). This reinforces the perception from the focus groups (Sherrington et al., 2008) that farmers don't know who to turn to for advice on perennial energy crops. However, the mean values do not tell the whole story. Table 20 lists the number who indicated that they would be likely or highly likely to follow the advice of specific salient referents.

Own experience/judgement	**55**
Agronomist	**45**
Existing SRC willow / miscanthus growers	**41**
Family	**41**
Other farmers	**38**
SRC willow / miscanthus producer groups	**35**
Biomass Energy Centre	**33**
NFU	**29**
Defra	**26**
Farming press	**24**
Power companies	**23**
Farmers clubs	**15**
Members of the public	**10**

Table 20: The number of respondents indicating that they would be likely or highly likely to follow the advice of specific salient referents.

It can be seen that in terms of non-family referents, the five most likely sources of advice are agronomists, existing SRC willow/miscanthus growers, other farmers, SRC willow/miscanthus producer groups, and the Biomass Energy Centre. This tends to support findings from the focus groups (Sherrington et al., 2008) that site visits and talking to existing growers are good ways of obtaining information, as is sharing information with other farmers through producer groups and co-operatives. It was thought by focus group participants that the Biomass Energy Centre had the potential to become a trusted source of information (Sherrington et al., 2008). To this can be added the suggestion that involving agronomists in open days organised by existing growers and producer groups would seem to be a reasonable way of promoting knowledge transfer among potential adopters.

Farmers do not, in general, seem to know a great deal about perennial energy crops. In response to the question of whether SRC willow will give a high gross margin, 64% were unsure, and for miscanthus, 67% were unsure. Unsurprisingly, in answer to the question of whether the likely costs and returns of SRC willow are easy to calculate, 80% were unsure, and 72% unsure for miscanthus. Likewise 85% were unsure whether the paperwork required to grow SRC willow to contract was easy, with 79% unsure about the paperwork required for miscanthus.

The finding that gross margin is not significantly correlated with behavioural intent for SRC willow, and is less significantly correlated than a number of other attitudinal factors for miscanthus is of importance for policy makers. It suggests that simply increasing the gross margin for perennial energy crops will not be an effective way of encouraging increased farmer uptake unless a number of issues such as those relating to security and stability of income from contracts are addressed. The proposed banding of the Renewables Obligation (DTI, 2007), intended to give a greater financial reward to those growing perennial energy crops, may not therefore bring about an increase in adoption unless the issues mentioned above are addressed at the same time.

16.0 Conclusion

It seems unlikely that the theoretical potential of perennial energy crops in the UK will be realised unless a number of barriers to adoption are overcome. For both SRC willow and miscanthus, these include concerns about the security and stability of income from contracts. Specifically in relation to SRC willow, farmers have concerns over disruption to cashflow, reduction in the flexibility of the farm business, and damage to field drains from willow roots.

While farmers in general don't consider that miscanthus or SRC willow will give a high gross margin, simply increasing the financial return from these crops without addressing the concerns outlined above is unlikely to result in widespread uptake.

In terms of further research, farm-level mathematical programming techniques will be used to identify the level of uptake that might be expected at different gross margins if the barriers identified in this paper are overcome, and assuming profit maximisation as the objective.

17.0 Acknowledgements

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18.0 References

ADAS, 2003. The mid-term evaluation of the England Rural Development Programme (ERDP): energy crop scheme.

Ajzen, I., 1991. The Theory of Planned Behaviour, Organizational Behaviour and Human Decision Processes 50, 179-211.

Ajzen, I., Fishbein, M., 1980. Attitudes, Personality and Behaviour. Open University Press, Milton Keynes.

Andersen, R.S., Towers, W., Smith, P., 2005. Assessing the potential for biomass energy to contribute to Scotland's renewable energy needs. Biomass and Bioenergy 29, 73-82.

Beedell, J., Rehman, T., 2000. Using social-psychology models to understand farmers' conservation behaviour, Journal of Rural Studies 16, 117-127.

Burton, R.J.F., 2004. Reconceptualising the 'behavioural approach' in agricultural studies: a socio-psychological perspective, Journal of Rural Studies 20, 359-371.

Carbon Trust, 2005. Biomass sector review, October 2005.

Charles, M.B., Ryan, R., Ryan, N., Oloruntoba, R., 2007. Public policy and biofuels: the way forward? Energy Policy 35, 5737-5746.

Council of the European Union, 2007. Presidency Conclusions, Brussels European Council, 8/9 May 2007.

DARDNI, 2007. Renewable Energy Action Plan. Department of Agriculture and Rural Development, Northern Ireland, January 2007.

Defra, 2006a. Creating value from renewable materials: a strategy for non-food crops and uses - two year progress report, Department for Environment, Food and Rural Affairs, 2006.

Defra, 2006b. Research to understand and model the behaviour and motivations of farmers in responding to policy changes (England) - Application and impact of the Single Payment Scheme: a Theory of Planned Behaviour analysis. Project Report no. 6, Research project EPES 0405/17, June 2006.

Defra, 2007. UK Biomass Strategy. Department for Environment, Food and Rural Affairs, May 2007.

DTI, 2003. Renewables Innovation Review, Department of Trade and Industry.

DTI, 2007. Renewable energy: reform of the Renewables Obligation. Department for Trade and Industry, May 2007.

Eagly, A. Chaiken, S., 1993. The Psychology of Attitudes, Harcourt Brace Jovanovich, San Diego.

Ericsson, K., Nilsson, L., 2006. Assessment of the potential biomass supply in Europe using a resource-focused approach. Biomass and Bioenergy 30, 1-15.

European Commission, 2007. Cereals: council approves zero set-aside rate for autumn 2007 and spring 2008 sowings, Press release, September 2007.

FAO, 2007. Crop prospects and food situation, No. 5, Food and Agriculture Organisation of the United Nations, Rome, October 2007.

Garforth, C., Rehman, T., McKerney, K., Tranter, R.B., Cooke, R.J., Yates, C.M., Park, J.R., Doward, P.T., 2004. Improving the design of knowledge transfer strategies by understanding farmer attitudes and behaviour, Journal of Farm Management 12, 17-32.

Mattison, E.H.A., Norris, K., 2007. Intentions of UK farmers toward biofuel crop production: implications for policy targets and land use change, Environmental Science and Technology 41 (16), 5589-5594.

RCEP, 2004. Biomass as a Renewable Energy Source; a limited report by the Royal Commission on Environmental Pollution, London.

Rosenqvist, H., Dawson, M., 2005. Economics of willow growing in Northern Ireland, Biomass and Bioenergy 28, 7-14.

SAC, 2007. Commercial viability of alternative non-food crops and biomass on Scottish farms - a special study supported under SEERAD Advisory Activity 211, March 2007.

Sherrington, C., Bartley, J., Moran, D., 2008. Farm-level constraints on the domestic supply of perennial energy crops in the UK, Energy Policy 36, 2504-2512.

Skytte, K., Meibom, P., Capral Henriksen, T., 2006. Electricity from biomass in the European Union - with or without biomass import? Biomass and Bioenergy 30, 385-392.

Strawson, J., 2005. Energy crops and the market for biomass in the UK. Nuffield Farming Scholarships Trust, January 2005.

Styles, D., Jones, M.B., 2007. Current and future financial competitiveness of electricity and heat from energy crops: a case study from Ireland. Energy Policy 35, 4355-4367.

Upham, P., Speakman, D., 2007. Stakeholder opinion on constrained 2030 bioenergy scenarios for North West England. Energy Policy 35, 5549-5561.

WAG, 2007. Personal communication from Vicky Davies, Rural Development Adviser, Technical Services Division, Welsh Assembly Government, Llandrindod Wells, 2007.

Chapter 4: Modelling farmer uptake of perennial energy crops in the UK

The research presented in this chapter has been published as Sherrington, C. & Moran, D., (2010) Modelling farmer uptake of perennial energy crops in the UK, Energy Policy (article in press). A CD containing the Excel models used in this study is included as an appendix

Abstract

The UK Biomass Strategy suggests that to reach the technical potential of perennial energy crops such as short rotation coppice (SRC) willow and miscanthus by 2020 requires 350,000 hectares of land. This represents a more than 20-fold increase on the current 15,546 hectares. Previous research has identified several barriers to adoption, including concerns over security of income from contracts. In addition, farmers perceive returns from these crops to be lower than for conventional crops. This paper uses a farm-level linear programming model to investigate theoretical uptake of energy crops at different gross margins under the assumption of a profit-maximising decision maker, and in the absence of known barriers to adoption. The findings suggest that while SRC willow, at current prices, remains less competitive, returns to miscanthus should have encouraged adoption on a wider scale than at present. This highlights the importance of the barriers to adoption. Recently announced contracts for miscanthus appear to offer a significant premium to farmers in order to encourage them to grow the crops. This raises the question of whether a more cost-effective approach would be for government to provide guarantees addressing farmers concerns including security of income from the contracts. Such an approach should encourage adoption at lower gross margins.

19.0 Introduction

In seeking both to tackle climate change and ensure that the UK has a secure supply of affordable energy, the UK Government is proposing a significant expansion in the generation of energy from renewable sources (DECC, 2009a). Under the Renewable Energy Directive, the UK is committed to the EU wide target to source 20% of the EU's total energy use from renewable sources by 2020. The UK's contribution towards this target is to provide renewable sources for 15% of its total energy use by 2020 (European Parliament and Council of the European Union, 2009). This would represent a ten-fold increase in levels of renewable generation over the next 12 years. The UK Government's Renewable Energy Strategy, which outlines how this level of generation could be achieved indicates that around 30% of the UK renewable energy target could come from biomass (DECC, 2009a)

The term 'biomass' covers a range of renewable fuels derived from organic matter, of which there are a number of possible sources in the UK. These include landfill gas, sewage gas, forestry, wood waste, conventional agricultural crops such as wheat and oilseed rape, straw, perennial energy crops, and agricultural waste (RCEP, 2004; Defra, 2007).

To increase available biomass, Defra (2007) favours obtaining an additional 1 million dry tonnes of wood per annum from woodland and wood waste, more use of manures and slurries, and a substantial growth in the uptake of perennial energy crops such as short rotation coppice (SRC) willow and miscanthus. Of these sources, it is the anticipated change in levels of perennial energy crops that is most dramatic, from under 16,000 hectares (ha) at present to 350,000 ha by 2020. This represents approximately a 20-fold increase, and would occupy roughly 6.5% of UK arable and set-aside land (Defra, 2007). The Renewable Energy Strategy is even more ambitious, with a supporting annex, looking at both arable and pasture land suggesting that the potential could be up to 2.2 million ha by 2030 (E4Tech, 2009).

Perennial energy crops can be considered as a novel enterprise for UK farmers, both in terms of their cultivation, and in their position at the interface between agricultural and energy policy. This brings a greater number of uncertainties than exist with conventional agricultural activities (Sherrington et al., 2008), and a number of financial and non-financial barriers to the adoption of such crops by UK farmers have been identified. These include concerns over the security and stability of income from contracts, disruption to cashflow, and reduced farm business flexibility (Sherrington et al., 2008; Sherrington and Moran, 2008). This paper builds on existing understanding by using a farm-level linear programming model to investigate theoretical uptake in energy crops at different gross margins (revenue minus variable costs) under the assumption of a profit-maximising decision maker, and in the absence of known barriers to adoption. The findings suggest that SRC willow at current prices remains unattractive for most farm types purely on a gross margin basis, even before accounting for concerns such as the impact of roots on field drains, and the security of the contracts available, although potential does exist for greater financial returns as the market for heat from SRC willow develops. Miscanthus, however, is currently more attractive on a gross margin basis, and the modelling suggests that adoption should, in theory, be widespread. There are fewer non-financial barriers to the adoption of miscanthus than SRC willow (Sherrington et al., 2008), and prices now available on contracts to supply miscanthus for co-firing at the UK's largest coal fired power station (Farmers Weekly, 2008; Farmers Guardian, 2008) make this crop considerably more attractive.

The paper is structured as follows. The next section compares estimates of the theoretical potential of perennial energy crops with actual uptake to date, before reviewing current understanding of barriers to energy crop adoption. The methodology for application of the linear programming model and its inputs are then described, and the results at the farm-level, and on aggregate, subsequently presented. A discussion section considers the results in the context of support for energy crops through energy and agricultural policies, and through contracts. A number of issues of policy significance are highlighted, followed by some recommendations and concluding comments.

19.1 Theoretical potential of energy crops in the UK

The theoretical potential of energy crops is estimated by Defra to be 17.2 TWh[9] (1.48 Mtoe)[10] per annum, while current availability is 0.07-0.09 Mtoe per annum (Defra, 2007). To reach this potential by 2020 would require 350,000 hectares (ha) of land, which is roughly 6.5% of UK arable and set-aside land, assuming an average annual yield of 9 oven dried tonnes (odt) per hectare (Defra, 2007). The Renewables Innovation Review (DTI, 2003), the original source of the above theoretical potential, suggests this is a realistic area once a number of constraints, including competition from other markets, are taken into account.

A recently developed range of energy crop scenarios used to inform the Renewable Energy Strategy suggests that by 2030, using both arable and pasture land, the potential could be up to 2.2 million hectares (E4Tech, 2009).

However, the actual realisation of the potential for these crops depends upon farmer behaviour – whether or not individual farmers choose to grow SRC willow and/or miscanthus. Experience to date suggests that farmer behaviour could be an important constraint on realising widespread uptake, on the scale identified by the estimates above.

Defra's Energy Crops Scheme, which provides establishment grants for SRC willow and miscanthus, was intended to support the planting, by 2006, of 16,700ha of SRC and 5000ha of miscanthus in England (ADAS, 2003). When the scheme closed to applications, in July 2006, only 1,180 hectares of SRC and 3,356 ha of miscanthus had been planted, however, increased interest in the payments, saw applications for

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[9] Terrawatt hours (One terrawatt is a trillion, or 10^{12} watts)

[10] Million tonnes of oil equivalent

planting in 2007 set to take the area of miscanthus to 12,627ha, and SRC to 2,600ha in England (Defra, 2006).

In Scotland, the area planted or approved for planting up until the end of 2006 was 300ha, with applications for planting in 2007 and 2008 amounting to around 600ha (SAC, 2007a). In Northern Ireland, 810ha of SRC have been planted or approved for planting (DARDNI, 2007), while in Wales there is known to be 40ha of SRC and 72ha of miscanthus (Welsh Assembly Government, 2007).

The latest published figure for the total area of perennial energy crops in the UK is 15,546ha for SRC willow and miscanthus combined (Defra, 2007), however it is believed that the planted area is now around 17,000ha (RELU, 2009).

19.2 Farmer attitudes and intentions towards the adoption of perennial energy crops

Focus group research involving existing and potential growers of SRC willow and miscanthus (Sherrington et al., 2008) revealed a broad consensus that the principle factor affecting a farmer's decision whether or not to grow perennial energy crops was perception of the level, and the security, of the financial return.

Of key importance to focus group participants was the establishment grant. Very few would consider growing perennial energy crops in the absence of the grant, due to high upfront costs and uncertainties over the resulting net income (Sherrington et al., 2008). However, the establishment grant has since been reduced from £1000/ha to a typical level of £665/ha for SRC willow, and from £920/ha to £800/ha for miscanthus (Jones, 2007). From the perspective of farmers taking part in the focus groups, this would make the crops less attractive.

Farmers felt that the lack of an incentive for renewable heat was a significant barrier to the development of energy crop supply, particularly for SRC willow. There was a keen awareness that the financial return could be greater if farmers were supplying local schools, hospitals or leisure centres. It was felt that supply to large electricity generators would never be the most financially attractive option. This view is supported by Valentine et al. (2008), who consider that SRC willow is currently undervalued, and that higher prices should be achievable as the market develops and the inherent energy value is fully recognised.

Follow up research (Sherrington and Moran, 2008) in the form of a wider postal survey of UK farmers' attitudes and behavioural intentions towards perennial energy crops identified that perception of financial return was not simply a question of anticipated gross margin. Of greater concern was the security and stability of income from contracts, disruption to cashflow, and reduced farm business flexibility. Specifically in relation to SRC willow, there were worries about damage to field drains from the roots.

The opportunity cost of growing perennial energy crops was also a concern to focus group participants. While the price of wheat and other annual crops has increased dramatically in recent years, the price offered for SRC willow and miscanthus was not felt to have risen much at all (Sherrington et al., 2008). Moreover, farmers are familiar with annual crops, for which there is a well developed market. While farmers may not always get the price they are expecting with wheat, they know they will at least be able to sell it, whereas for perennial energy crops, the lack of a developed market means farmers are concerned about being left with a crop that no-one will buy. The majority of focus group participants felt it was difficult to calculate the returns from energy crops due to uncertainty over costs, yields and prices. In contrast, farmers were very aware of returns from conventional annual crops and at what prices and yields they would be profitable (Sherrington et al., 2008). There is also the issue of flexibility, with farmers valuing the ability to switch crops year on year - something that would not be possible on land committed to perennial energy crops (Sherrington et al., 2008).

University of Cambridge (2005) identifies that farmers are often reluctant to switch from one annual crop with which they are familiar to another less familiar annual crop. This inertia means that farmers may not immediately switch on the basis of an increased gross margin. For miscanthus and SRC willow the differences are greater still. SAC (2007a) states that for most farm businesses SRC willow remains unattractive due to the long term commitment required, loss of cropping flexibility, and limited market. It is suggested that to overcome these issues and achieve large scale plantings, SRC willow returns would have to significantly exceed those achievable in conventional arable systems (SAC, 2007a).

However, estimating the required level of return is very difficult as the risks involved in growing perennial energy crops are of a different kind to those associated with annual crops. Comparison of two annual crops might be based on their average yield and price over a number of years, and the variance of those factors, with a higher variance indicating a greater risk. For perennial energy crops there is no such track record of yield and price to which farmers can refer with confidence. Indeed, along with yield and price risk, there is regulatory risk, arising from both agricultural and energy policy. The suspension of the establishment grant and the subsequent lowering of the payment level is an example of the former, while ongoing amendments as to the status of co-firing within the RO (Sherrington et al., 2008), and subsequent banding of ROCs (OPSI, 2009) are examples of the latter. There is also institutional risk, in terms of the confidence that farmers have in the security of payments available through contracts (Sherrington et al., 2008).

While difficult to model, the fact that farmers' perceptions of the risks associated with perennial energy crops have been identified is an important step. As Meijer et al. (2007) point out, identifying dominant sources of uncertainty can deliver valuable insights for policy makers, who may choose to act to tackle these barriers to adoption. Sherrington et al., (2008), for example, suggest that farmer confidence in the security of the contracts could be increased through government underwriting or some form of insurance.

This paper therefore abstracts from these uncertainties, and looks at the level of financial return required to motivate farmers to adopt perennial energy crops under the assumption of a profit maximising decision maker, and in the absence of previously identified barriers.

20.0 Methodology for application of the farm level model

A generic linear programming model for farm-level analysis, developed at the Scottish Agricultural College (SAC) was used to assess the likely uptake of perennial energy crops at different gross margins under the assumption of a profit maximising decision-maker, as outlined above. The model can be calibrated to represent any particular farm situation, in terms of basic resource endowments, and run using Visual Basic for Applications and Microsoft Excel Solver to simulate representative or real farm situations. The model has been used in various studies, e.g. Revell and Oglethorpe (2003), to analyse the economic impacts of policy developments on farm businesses, particularly relating to how enterprise substitutions may occur. The model incorporates all major cropping and livestock activities carried out on UK farms and can thus be calibrated for all mainstream farming types (University of Cambridge, 2005). The objective function of the model is to maximise the overall farm gross margin (revenue minus variable costs) in a single year (SRC willow and miscanthus gross margins are therefore represented as annual equivalent values) within the constraints of available resources such as land, labour and machinery.

Gross margins are not explicitly entered into the model for conventional crops, but are implicit from the variable costs involved in production, relating for example to seeds, fertiliser, and herbicides, and the revenue based on the yield and the prices received. For the purposes of this exercise, energy crops are included in the model as an extra activity available to the farmer. This energy crop option does have an explicit gross margin. The model proceeds through a number of runs, with the objective of maximising the whole farm gross margin. With each run of the model, the gross margin attributed to energy crops is gradually increased, and the effect of this on the amount of land allocated to energy crops is observed. Having identified the gross margin that is necessary to bring about a certain level of uptake, the price/yield/subsidy combination necessary to achieve such a gross margin is considered.

Fixed costs are included in the modelling in order to calculate a net margin for SRC and miscanthus, but the allocation of land to energy crops in the model is determined simply by the energy crop's gross margin. It is considered likely that for most farmers the establishment and harvesting of perennial energy crops will be undertaken by contractors (University of Cambridge, 2005; Sherrington et al., 2008), and this is reflected in the model where these activities make no call on the farm's labour or machinery resources. For conventional crops, however, farms have a choice of using on-farm machinery and labour, which is effectively a fixed-cost aspect, or alternatively, once these resources are fully allocated, contractors and related machinery can be brought in. It is worth noting that the use of contractors for conventional crops represents a variable cost attributed to the specific activity, and will therefore reduce the gross margin of that particular activity.

It was decided not to attempt explicitly to consider risk within the model because, as outlined above, the risks associated with growing perennial energy crops are different from those related to conventional crops. In addition to potential variations in price and yield, a number of specific concerns stem from the position of perennial energy crops at the interface of agricultural and energy policy. Alongside this changing regulatory framework is the perceived institutional risk associated with contracts. The approach taken, therefore, is to abstract from these previously identified risks (Sherrington et al., 2008; Sherrington & Moran, 2008) and examine theoretical uptake under the assumption that these barriers to adoption had effectively been tackled through policy intervention.

While this approach was taken for the purposes of this assessment, for future work, risk could be included within the model using, for example, Monte Carlo methods. Under this approach, probability distributions could be described for the prices available for competing activities. In addition, such techniques could be used to account for risk in the production of energy crops, such as for the cost of inputs, harvesting, and indeed the yield that might be expected.

The model was used by University of Cambridge (2005) to predict uptake of perennial energy crops at different gross margins across four of the major farm types (cereal farms, mixed farms, general cropping farms, cattle and sheep (lowland) farms). However, in the context of the subsequent significant global rise in the price of agricultural commodities such as wheat (FAO, 2007, Farmers Weekly, 2009b) and the role that biomass is due to play in the UK Government's approach to tackling climate change (DECC, 2009a) it is important to reassess the gross margins that would be required to stimulate production to the level necessary to meet the theoretical potential. The four representative farm types are distinguished in the model principally on the basis of the number of hectares of different land types available for different activities. As in the University of Cambridge (2005) study, each of the farm types were split into three size groups based on classifications from the Farm Accounts in England (Defra, 2002) (see Table 21). As with the University of Cambridge (2005) study, within the model energy crop production can only occur on tillable land. It is recognised that this is a simplification in that some farmers may choose to plant perennial energy crops on less productive soils, although the yield and therefore gross margin would be lower in these cases.

Farm Type	Size	Total area farmed (ha)	Semi-natural pasture/rough grazing (ha)	Permanent pasture (ha)	Tillable land (ha)
Cereal	**Small**	**60**	**0.5**	**8.7**	**50.8**
	Medium	**143**	**1.1**	**13.5**	**128.4**
	Large	**392**	**1.2**	**21.5**	**369.3**
Mixed	**Small**	**90**	**0.1**	**29**	**60.9**
	Medium	**125**	**0.5**	**37.1**	**87.4**
	Large	**286**	**6.6**	**69.6**	**209.8**
General cropping	**Small**	**68**	**0**	**4**	**64**
	Medium	**88**	**0.1**	**8.7**	**79.2**
	Large	**359**	**3.7**	**23.4**	**331.9**
Cattle & sheep (lowland)	**Small**	**80**	**2**	**51.2**	**26.8**
	Medium	**121**	**0.1**	**78**	**42.9**
	Large	**205**	**5**	**91.4**	**108.6**

Table 21: Farm types used in modelling exercise

With an increase in agricultural commodity prices over the past few years, UK farmers are now achieving higher gross margins for a number of conventional crops. A typical gross margin for winter wheat, for example, has increased from £301/ha (University of Cambridge, 2005) to £738/ha (SAC, 2007b). While the prices achieved for such crops have increased considerably, the focus group participants suggested that prices offered for energy crops have failed to keep up. Prices, and input costs, for conventional activities included in the model (see Table 22) were updated using the 2007/08 edition of the Farm Management Handbook (SAC, 2007b), and the analysis re-run to investigate the gross margins that would have to be achieved by energy crops to bring about adoption.

	Winter Wheat	Winter Barley	Winter Oats	Oilseed Rape	Field Beans
YIELD					
Yield (Grain/Seed) (t/ha)	8	7.5	7.5	4	5
Yield (straw) (t/ha)	5.2	5.6	6.4		
OUTPUT					
Grain/seed (£/t)	115	105	105	185	135
Straw (£/t)	25	30	35		
Grain/seed (£/ha)	920	788	788	740	674
Straw (£/ha)	130	168	224		
Total output (£/ha)	1050	956	1012	740	674
VARIABLE COSTS					
Seed (£/t)	275	270	290	7000	350
Seed (£/ha)	63	59	55	45	88
Fertiliser	143	134	98	127	31
Contract				48	48
Sprays	92	60	59	84	91
Other crop expenses	14	15	17		
Total Variable Costs (£/ha)	312	268	229	304	258
GROSS MARGIN	738	688	783	436	417

Table 22: Yields, Outputs, Variable Costs and Gross Margins of Conventional Crops (Source: Farm Management Handbook (SAC 2007b)

Prices were based on a single year rather than taking a weighted mean of prices over 5 years, as it was felt that doing so would not accurately reflect the price expectations of farmers. Among focus group participants (Sherrington et al., 2008) there was much speculation (and some excitement) as to how high the wheat price might go. UK wheat futures rose from around £90/t in January 2007 to a peak of £190/t in March 2008. While they have subsequently fallen back, the current futures price for feed wheat for delivery in November 2010 is £115/t (Farmers Weekly, 2009a), which is well above the five year average. Moreover, the OECD's outlook for the next decade is that agricultural commodity prices will remain at a higher level than in the past ten years (Farmers Weekly, 2009b). Therefore, the prices used in the model, as shown in Table 23, while above the five year average, are well below the peaks of recent years.

Activity	Price (£/t) 2002-03	Price (£/t) 2007-08
Winter wheat	**70**	**115**
Winter barley	**66**	**105**
Winter oats	**56**	**105**
Oilseed rape	**144**	**185**
Field beans	**74**	**135**

Table 23: Comparison of conventional crop prices between 2002/03 and 2007/08 (Source: Farm Management Handbook (SAC 2002; SAC 2007b)

A simple budgeting analysis would suggest that new activities would have to provide gross margins greater than those for alternative crops in order to be adopted. However, agronomic and practical constraints prevent farmers from growing a single but profitable crop. Instead, crop interactions within a rotation give rise to an optimum combination of crops within a farm business. One advantage for SRC willow and miscanthus in this respect, as perennial crops, is that they fall outside of any rotational constraints.

20.1 Energy crop cost, yield and price assumptions

All periodic variable costs such as harvesting, and assumptions relating to yield, for both SRC willow (9odt/ha/yr) and miscanthus (14odt/ha/yr), are held at the same levels as the standard assumptions used by University of Cambridge (2005). For SRC willow at 9/odt/ha/yr the contract costs for each harvest are taken to be £311/ha. The marketing costs (for loading, weighbridge charges and moisture testing) are £135/ha (£5/odt), and the handling & drying costs are £162/ha (£6/odt). This gives total variable costs in the harvest year of £608/ha, or approximately £203 on an annual basis.

For miscanthus, assuming yields increase up to 14odt/ha/yr, the contract costs for each harvest are taken to be £92/ha. The marketing costs are £45/ha (£3.20/odt), and the handling & drying costs are £56/ha (£4/odt). This gives total variable costs in the harvest year of £193/ha. These cost figures, for both SRC willow and miscanthus, are consistent with those currently used by the TSEC-Biosys programme, and have been validated through discussions with industry (Bauen, 2008).

The establishment costs and associated grants, however, are updated to take account of the more recent work for Defra by Jones (2007). The ex-farm price for SRC willow has been increased to £40/odt, to represent contracts currently available to farmers in the vicinity of Drax power station (CRL, 2008). The ex-farm price for miscanthus has been increased to £60/odt, as per contracts now available to farmers wishing to supply Drax (Farmers Weekly, 2008). These costs and assumed revenues over a 16 year period are discounted at 6%, representing the farmer's cost of capital, to give a net present value (NPV) and an annual equivalent value (AEV). The AEV represents the gross margin when making the comparison with conventional annual crops.

21.0 Results

This section first presents the calculated likely gross margins for SRC willow and miscanthus, followed by model results showing the gross margins that would be required to achieve a certain level of uptake.

21.1 Energy crop gross margins

As with any discounted cashflow model, increased costs in the year of establishment (Year 0), have a greater impact on the NPV and AEV than any increases in subsequent years. The figures presented by Jones (2007) mean that SRC willow delivers a lower gross margin under standard assumptions (see Table 24) than previously reported by University of Cambridge (2005), even when increasing the price from £35/odt to £40/odt. If the price were taken to be £44/odt, then the gross margin is £98/ha, barely changed from the University of Cambridge (2005) figure. It is of interest, however, to consider the impact of an increase in the price for SRC willow to levels suggested by Valentine et al. (2008). The authors suggest that £45-60/odt is a more realistic price in terms of the developing market. This would deliver a gross margin of between £106/ha and £221/ha. A higher potential value of £75/odt is suggested as better representing the inherent energy value. This would deliver a gross margin of £337. However, for the purposes of this exercise, the use of the £40/odt figure is justified as this represents what is currently available on a large scale contract.

		University of Cambridge (2005)	Amended establishment costs and grant level as per Jones (2007)
Price	**£/odt**	**35**	**40**
Yield	**odt/ha/yr**	**9**	**9**
Energy crop payment	**£/ha**	**30**	**30**
Establishment costs	**£/ha**	**1273**	**1663**
Establishment grant	**£/ha**	**1000**	**665**
Gross margin	£/ha	97	67

Table 24: Effect of revised establishment costs and grant levels on Gross Margin of SRC willow under standard assumptions

Miscanthus, on the other hand, now shows a greatly increased gross margin of £444/ha based on the significant increase in price to £60/odt (see Table 25). However, it is not clear whether this price would be offered for supply to facilities other than Drax. Had the price remained at £25/odt, the effect of the revised establishment costs and grant levels would have been to reduce the gross margin to £35/ha. Working on the estimated price quoted by Nix (2007) of £35/odt, the gross margin would be £152/ha.

		University of Cambridge (2005)	Amended establishment costs and grant level as per Jones (2007)
Price	**£/odt**	**25**	**60**
Yield	**odt/ha/yr**	**14**	**14**
Energy crop payment	**£/ha**	**30**	**30**
Establishment costs	**£/ha**	**1691**	**2000**
Establishment grant	**£/ha**	**920**	**800**
Gross margin	£/ha	75	444

Table 25: Effect of revised establishment costs and grant levels on Gross Margin of miscanthus under standard assumptions

21.2 Modelled uptake

The figures below show the uptake for each farm type and size, for 2002/03 prices of competing activities and for 2007/08 prices. In general terms, the higher prices obtained for conventional crops in 2007/08 have led to an increase in the gross margin that is required before energy crops are adopted. Once they are adopted, the models show smaller proportions of the farm being allocated to energy crops in the 2007/08 scenarios for a given gross margin. This is in line with the intuitive assumption that higher prices for alternative crops would increase the return required from energy crops before adoption.

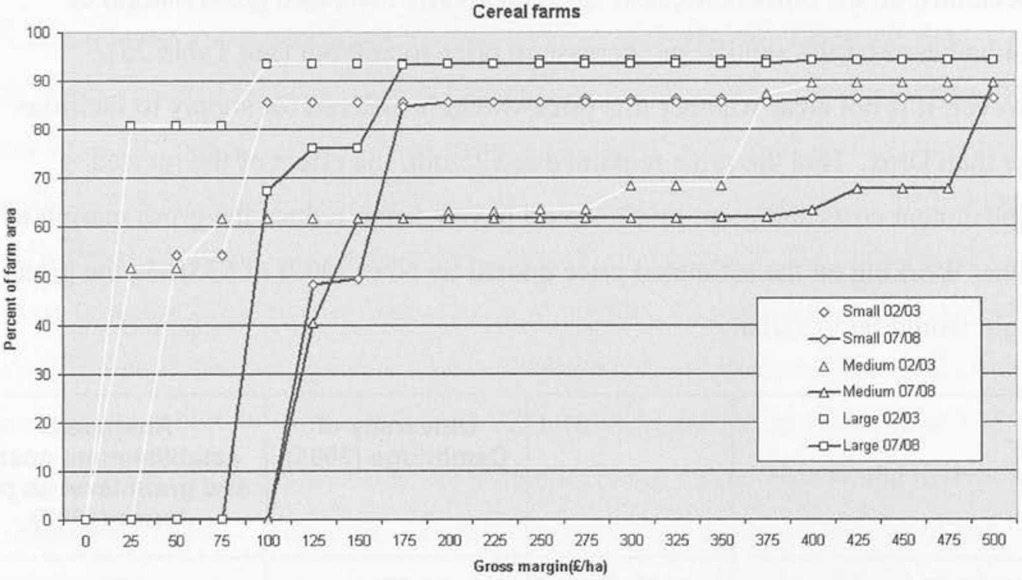

Figure 5: Uptake of perennial energy crops on cereal farms

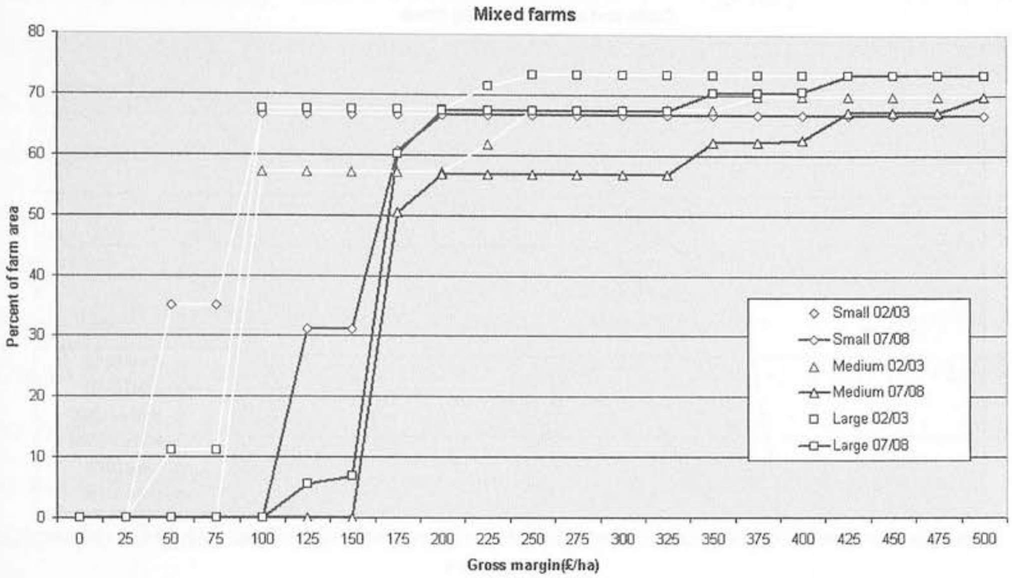

Figure 6: Uptake of perennial energy crops on mixed farms

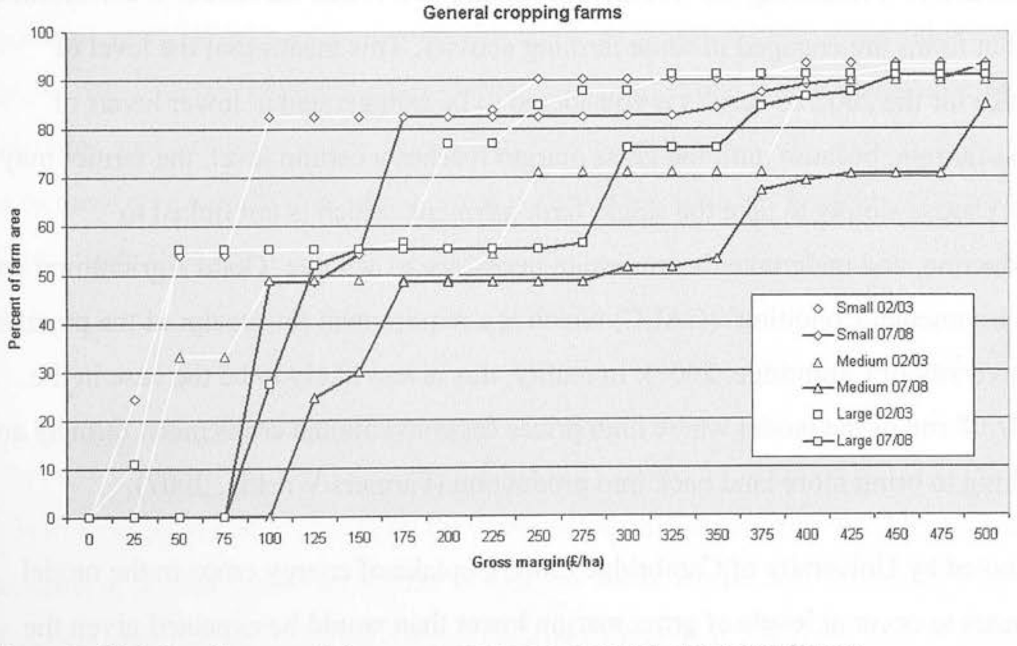

Figure 7: Uptake of perennial energy crops on general cropping farms

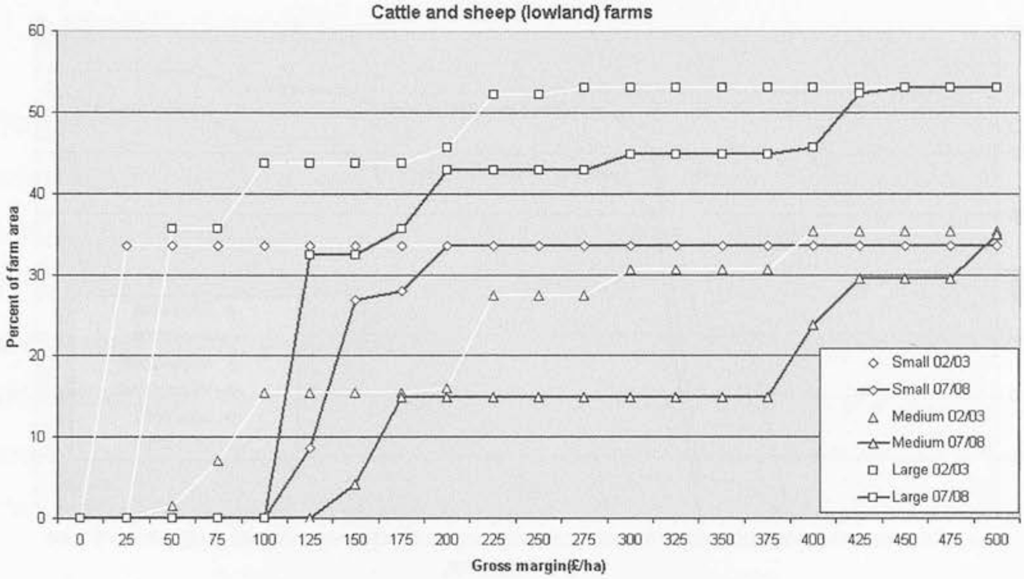

Figure 8: Uptake of perennial energy crops on cattle and sheep (lowland) farms

As with all linear programming models, understanding the underlying assumptions is important in interpreting the results. One assumption is that the model is constrained so that farms are engaged in some farming activity. This means that the level of uptake for the 2002/03 results is considered to be exaggerated at lower levels of gross margin, because until the gross margin reaches a certain level, the farmer may well choose simply to take the single farm payment, which is not linked to production, and undertake the minimum necessary to achieve 'Good Agricultural and Environmental Condition' (GAEC) which is a requirement for receipt of the payment (University of Cambridge, 2005). In reality, this is less likely to be the case in the 2007/08 run of the model where high prices for conventional crops mean farmers are seeking to bring more land back into production (Farmers Weekly, 2007).

As noted by University of Cambridge (2005), uptake of energy crops in the model appears to occur at levels of gross margin lower than would be expected given the gross margins of conventional crops. With gross margins of £125/ha, most of the farm types/sizes modelled have adopted energy crops to some extent, and by £150/ha, all but one of the models have done so. This is related to the fact that the energy crop gross margins include the costs of machinery and labour as most work is undertaken through contract. In the model farms have a choice of using on-farm machinery and labour, which is effectively a fixed-cost aspect, or alternatively, once these resources are fully allocated, contractors and related machinery can be brought in, but these will represent a variable cost attributed to the specific activity, and will therefore reduce the gross margin of that particular activity. It is noticeable in this respect that larger farms generally seem to have lower thresholds for uptake. A large proportion of cereals are grown with the use of contractors on the larger farms, which reduces their gross margin accordingly and therefore reduces the level of gross margin necessary before energy crops become viable, and leads to higher uptake at lower gross margins (University of Cambridge, 2005). This reflects the reality that on farms where there is an existing labour force and sufficient machinery to undertake all tasks, energy crops are less likely to be adopted. If they were, and contractors were brought in to do the work (and focus group findings suggested that farmers would almost always want a contractor to undertake the specialised work), the fixed labour costs would still have to be paid even if staff were standing idle.

The model also shows major changes in cropping with relatively small changes in the gross margin of energy crops. Again, this is due to the underlying assumptions within the model, such that once the gross margin for energy crops is higher than alternative activities, large changes occur. In practice, this is thought unlikely to take place due to farmers' aversion to risk, which is not considered within the model (University of Cambridge, 2005).

21.3 Aggregate levels of uptake

It is of interest to investigate what the observed results at the farm-scale might mean in terms of production on a regional or national basis. At the simplest level, this involves aggregation of the farm-level results. However, it is important to note that when reporting farm-level results, no account is taken of longer term market conditions, and the 'small firm' case prevails where no endogenous changes in demand or supply are implemented by the model. Therefore, as supply levels shift, the resultant changes in price are not accounted for, and should be borne in mind when interpreting such aggregated estimates (Revell and Oglethorpe, 2003).

Table 26 shows the results for each of the 12 farm type and size combinations when aggregated using data on the number of such businesses in England from the June Census (Defra, 2002). These indicate that on comparison of financial returns alone, and abstracting from known barriers to adoption, the theoretical potential of 350,000ha for the UK as a whole (Defra, 2007) should readily be achieved.

Type of Farm	Size	Average size (ha)	Number of Farms	Total area (ha)	% uptake at GM of £100/ha	Total area of energy crops (ha)	% uptake at GM of £125/ha	Total area of energy crops (ha)	% uptake at GM of £150/ha	Total area of energy crops (ha)
Cereals	Small	60	5,653	339,180	-	-	48	162,806	49	166,198
	Medium	143	5,045	721,435	-	-	40	288,574	61	440,075
	Large	392	4,085	1,601,320	67	1,072,884	76	1,217,003	76	1,217,003
Mixed	Small	90	3,015	271,350	-	-	31	84,119	31	84,119
	Medium	125	2,091	261,375	-	-	-	-	-	-
	Large	286	1,981	566,566	-	-	5.6	31,728	7	39,660
General Cropping	Small	68	1,796	122,128	48	58,621	48	58.621	54	65,949
	Medium	88	2,569	226,072	-	-	24	54,257	30	67,822
	Large	359	3,278	1,176,802	27	317,737	52	611,937	55	647,241
Cattle & Sheep (Lowland)	Small	80	7,545	603,600	-	-	8	48,288	27	162,972
	Medium	121	1,384	167,464	-	-	-	-	4	6,699
	Large	205	436	89,380	-	-	32	28,602	2	1,788
Total area (ha)				**6,146,672**		**1,449,242**		**2,585,935**		**2,899,525**

Table 26: Modelled aggregate uptake of energy crops over four farm types in England at different gross margins

Taking the estimated price quoted by Nix (2007) for miscanthus of £35/odt to be representative of what has been available to farmers in recent years, the gross margin would typically be £152/ha. At this level, as shown in Table 26, the models show an aggregate uptake of almost 2.9 million hectares, which is over eight times the theoretical potential as considered by Defra (2007). While this is likely to be an exaggerated level, as it does not account of any changes in price as a response to increased supply, notwithstanding the general reluctance on the part of farmers to make large changes to their cropping plan simply on the basis of a more competitive gross margin, it does demonstrate that for many farms, a crop providing these returns, using a price at the lower end of what is currently available, should be attractive. The most recent available figures on miscanthus uptake indicate an area of 12,627ha in England (Defra, 2006), which is less than 0.5 % of the modelled level.

22.0 Discussion

It is possible to identify from Figure 5, Figure 6, Figure 7 and Figure 8, the general trend in uptake of the energy crop option, resulting from increased prices for conventional activities. One might quite reasonably assume that taking an average of prices between 2002/03 and 2007/08 might generate levels of energy crop uptake that follow the same trends, but lying between the levels shown for the different years. The results of this model should not, however, be taken as a forecast for a number of reasons that have been outlined in the text. These include the novel nature of the crops, the lack of an established market, and the associated risks as perceived by farmers.

Previous research has identified that in general there tend to be fewer barriers to the adoption of miscanthus than there are for SRC willow (Sherrington et al., 2008). Even so, miscanthus is clearly not yet an attractive crop for farmers to the extent that might be expected given the current estimated level of return. This discrepancy between the modelled results and the area of land that has actually been committed to miscanthus, which is also due in part to the limited number (and distribution) of dedicated biomass and co-firing power stations, highlights the significance of these barriers and the threat that they pose to the attainment of the technical potential of perennial energy crops in the UK (Defra, 2007).

The actual supply response of UK farmers to perennial energy crops, given the current energy and agricultural policy environment, is clearly going to be different from the modelled supply response. Farmers perceive these novel crops to present a greater risk than conventional annual crops, for numerous reasons outlined above, and will not simply switch to them when the predicted gross margin is slightly higher than for an existing activity. For most farmers, there should, however, come a point when the price offered for miscanthus or SRC willow is sufficiently high to overcome these other concerns. When this occurs, in effect, payment will accurately reflect the premium for the risk that individual farmers believe they are taking. An interesting example to observe will be farmer uptake of the £60/odt contracts for miscanthus offered by Bical for supply to Drax (Farmers Weekly, 2008). Over time, increased uptake and farmers' increased familiarity with the crops should act to reduce the required risk premium.

The prices offered by these contracts have been calculated in this paper to deliver a gross margin of £444/ha. While this may well be sufficiently attractive to enough farmers for Drax's supply expectations to be realised, it would seem, from the model, that a considerable risk premium is being paid. It is therefore worth assessing the impact of current agricultural and energy policy on the perception of risks relating to these crops, the extent to which this is dealt with in contracts, and considering what approaches might serve to lower the perceived risks, and thus lessen the barriers to adoption.

22.1 Agricultural policy support for perennial energy crops

A number of grants have been available to farmers throughout the UK for the establishment of SRC willow and miscanthus with an energy end use in mind. In England, the Energy Crops Scheme (ECS) under the 2000-2006 England Rural Development Programme (ERDP) offered £1000/ha for SRC willow and £920/ha for miscanthus. This scheme closed to applicants in the summer of 2006, and has been superseded by a new ECS (2007-2013), which opened in October 2007.

The main difference with the new scheme is that for both SRC and miscanthus, payment will be based on 40% of actual establishment costs instead of a fixed hectarage basis (Natural England, 2007). Taking Defra's estimate of typical establishment costs for SRC of £1663 (Jones, 2007) the grant will be reduced from £1000/ha to £665/ha. For miscanthus, the estimate of establishment costs is £2000/ha (Jones, 2007), and thus the grant will be £800/ha.

Sherrington et al. (2008) identified that the establishment grant is of key importance to focus group participants. Very few would consider growing perennial energy crops in the absence of the grant, due to high upfront costs and uncertainties over the resulting net income (Sherrington et al., 2008). While farmers still have concerns over the security of income from energy crop contracts (Sherrington et al., 2008; Sherrington and Moran, 2008), this reduction in the level of upfront support does not appear to be consistent with the aim of encouraging a wider uptake (Defra, 2007). From the perspective of farmers taking part in the focus groups, this would make the crops less attractive.

22.2 Energy policy support for energy crops

The Renewables Obligation (RO) is the UK Government's key policy mechanism for increasing the proportion of electricity derived from renewable sources. Under the scheme there is a mandatory requirement for UK electricity suppliers to source a growing percentage of electricity from eligible renewable generation capacity.

In April 2009, the RO changed from being 'technology neutral, awarding ROCs for every MWh of electricity produced from any eligible renewable source, to providing different levels of support to different technologies through 'banding'. Technologies are now grouped in 'bands', receiving 0.25, 0.5, 1, 1.5 or 2 ROCs per MWh, based on their level of development and generation costs. This is to encourage a greater diversity of renewable technologies and give greater support for those technologies that are currently less cost-effective. Under the amended Obligation, co-firing of regular (non-energy crop) biomass, considered an established technology, receives a reduced level of support of 0.5 ROCs, while co-firing of energy crops is awarded 1 ROC for every MWh. Dedicated regular biomass receives 1.5 ROCs, while energy crops in dedicated biomass burners or in combined heat and power (CHP) receive 2 ROCs (OPSI, 2009).

Valentine et al. (2008) calculate that this additional 0.5 ROC payment for energy crops should be worth £28.81 per odt to electricity generators. This is based on the 2007/08 ROC buyout price of £34.30 (BWEA, 2008) and a value to generators of 1.68MWhe/odt (assuming wood at 35% moisture and with 35% conversion efficiency) (Valentine et al., 2008). This figure does not seem to account for a typical supplier margin, with the average of industry data showing that 88% of the ROC value is actually received by generators, the remaining 12% being held by the suppliers of electricity to end consumers (Carbon Trust, 2005). However, with the current traded ROC price of approximately £53/MWh (NFPA, 2009), it could be assumed that the additional 0.5 ROCs is worth approximately £39 per odt to generators. How much of this value might then be passed through to energy crop growers is uncertain.

Sherrington and Moran (2008) conclude that while farmers in general don't consider that miscanthus or SRC willow will give a high gross margin, simply increasing the financial return from these crops without addressing the concerns relating to security of contracts and stability of income is unlikely to result in widespread uptake. However, this is precisely what has happened with banding of the Renewables Obligation, which gives electricity generation from energy crops a higher level of support than for electricity generation from regular biomass (OPSI, 2009). This support is in fact directed towards the electricity supplier rather than the farmer, but the expectation is that the higher prices should, via the generator, feed through to farmers and increase uptake (Valentine et al., 2008).

In combination with changing agricultural policy support, it can be seen that there has been a shift in emphasis away from up-front and direct funding to the farmer via establishment grants towards the 'indirect' funding of electricity generation from perennial energy crops, which should theoretically deliver increased revenues to the farmer four years after initial establishment of the crops. While farmers have concerns over the security of income through currently available contracts, this will serve to reduce the effectiveness of increasing the potential financial return.

Heat generation from energy crops has long been recognised by the Government as an efficient way to reduce carbon emissions (DTI & Defra, 2006), and The Energy Act 2008 (HMSO, 2008) allowed for the setting up of a Renewable Heat Incentive (RHI). This is due to be introduced in April 2011, and will provide support for the use of perennial energy crops for heat generation at all scales. (DECC, 2009b). Farmers participating in the focus group discussion felt that the lack of an incentive for renewable heat was a significant barrier to the development of energy crop supply, particularly for SRC willow. It was strongly felt that the financial return could be greater, and contractual security improved, if farmers were supplying local schools, hospitals or leisure centres (Sherrington et al., 2008).

22.3 Contracts available for SRC willow and miscanthus

Coppice Resources Ltd (CRL) offered farmers contracts, in 2007, to supply Drax, with Retail Price Index (RPI) linked payments for the harvested crop of around £37.50/odt (ex-farm at 35% moisture content) (CRL, 2007). These have since been increased to £40/odt (CRL, 2008). CRL also offer a contract for supply to the Biojoule pellet plant, at £15/odt for the standing crop, with all harvesting, handling and haulage costs covered by CRL. A further contract is available to supply the Sembcorp Wilton 10 power station on Teeside. In 2007, this offered £41.50/odt (delivered price at £35% moisture content). This has since been increased to £61/odt, but a formula is used to account for the amount of fuel needed to dry the chip down (CRL, 2008). At 35% moisture content, and using CRL's assumption of £12/odt for haulage costs, the price equates to approximately £44/odt ex-farm. As of October 2008, CRL has no growers lined up to supply SRC willow to Drax, Biojoule, or Sembcorp Wilton 10 (CRL, 2008).

Valentine et al. (2008) consider that current prices offered for SRC willow do not fully reflect the value of the crop. In their analysis they consider £45-60/odt to be a more realistic price in terms of the developing market, and £75/odt a higher potential value based on inherent energy value. The forthcoming RHI raises the likelihood that prices for SRC willow will indeed increase in future years.

Nix (2007) quotes a price range for miscanthus of £25-£45 per odt, based on information supplied by Bical, and uses £35/odt to illustrate a gross margin calculation. More recently, a price of £60/odt ex-farm has been quoted as available through Bical to supply Drax (Farmers Weekly, 2008; Farmers Guardian, 2008). This represents a substantial improvement on the previous prices available for miscanthus

It is not clear, however, that this price will become available to farmers wishing to supply facilities other than Drax. As an independent power producer operating one 4000MW coal fired power station, they are not representative of the vertically integrated power companies that constitute the majority of the UK's electricity generation. Drax's expenditure on carbon allowances within the EU Emissions Trading Scheme increased from £11 million in the first six months of 2007, to £107 million in the first six months of 2008. This is due both to a reduction in the number of free allocations awarded to Drax under Phase II, and an increase in the cost of the allowances that must be purchased (Carbon Finance, 2008). This would have the effect of making combustion of biomass relatively more attractive due to the benefits of avoided carbon costs. While the carbon neutrality of biomass under the EU-ETS increases its attractiveness to all power producers, other generators with a less carbon intensive mix of coal, gas and renewable generation may not be under such pressure.

Importantly, Bical has introduced a scheme for deferred payment of 43% of the first two year's costs (Farmers Weekly, 2008). The deferred payment scheme would also appear to address one of the key concerns that farmers have about perennial energy crops, which is the issue of cashflow difficulties in the period before the first harvest (Sherrington et al., 2008). The reduction in the establishment grant will have made this deferred payment scheme even more important.

22.4 Tackling barriers to uptake in a cost-effective manner

Widespread adoption of energy crops could bring societal benefits in terms of both cost-effective reductions in carbon emissions, and increased security of energy supply.

Use of perennial energy crops, and in particular using SRC willow for heat generation has been demonstrated to be a cost-effective approach to reducing carbon emissions (University of Cambridge, 2005). There are also some important arguments in relation to security of energy supply that cannot readily be incorporated into models as presented in this paper. All things being equal, it might be expected that UK citizens would place a premium on an energy source that was guaranteed to contribute to UK supply, as opposed to imports of, for example, natural gas that are seen as 'less secure'. While there is a lack of empirical evidence that would enable such a premium to be modelled in respect of potential future uptake, in future years it may well be that such a premium becomes apparent, to the benefit of UK growers of energy crops.

However, current farmer perception of the risk involved in growing perennial energy crops, allied with the way agricultural and energy policy is formulated threatens to either:

a) Prevent such potentially cost-effective carbon reduction options taking place (at least on anything other than a relatively small scale); or
b) Increase the overall cost of reducing emissions in this way. Through the approach of increasing the contract price to such a point that it provides sufficient risk compensation for individual farmers to adopt such crops, the cost-effectiveness of this measure as a way of reducing carbon emissions, decreases.

The results from the modelling show that without the barriers to adoption, farmers would adopt energy crops at a lower gross margin than they would require at present given the perception of risk that exists. This leads to inefficient outcomes at the societal level. Farmers miss out on an opportunity to diversify and establish new markets, energy suppliers (and ultimately consumers) pay higher prices than they otherwise would, and an opportunity to abate carbon at a lower cost is foregone.

There are a number of potential advantages for society as a whole that arise when risks in agriculture are shared, through routes such as insurance, marketing contracts, or external equity financing (Meuwissen et al., 2000). One key benefit is that the possibility of sharing risks permits individuals to engage in risky activities, which they would otherwise not undertake. In so doing, the expected return to society is increased over what would prevail if individual agents were constrained to accept only those risks they could afford themselves to bear (Arrow, 1992; Hardaker et al., 1997; Rejda, 1998). In addition, if farmers can trade away part of their risks so that they can move closer to the point of expected profit maximisation – but not fully because there are costs involved – the result will be a more socially desirable allocation of resources (Myers, 1988). Moreover, if farmers need to put less effort into on-farm methods of avoiding risks, they might well be able to use their resources more efficiently, which in turn implies greater overall efficiency in resource use (Hardaker et al., 1997; Rejda, 1998).

In the context of perennial energy crops, a form of insurance available to growers that would serve to reduce concerns about the security and stability of incomes from contracts, would have the wider societal benefit of enabling cost-effective reductions in carbon emissions, alongside the potential energy security benefits. Until the market becomes more established, there is arguably a role for Government in acting as guarantor, or at least becoming more actively involved in the provision of a form of insurance.

While no such scheme has, to the author's knowledge, been proposed, it could potentially be in the form of a bond that is placed in the hands of a third party (perhaps a Government Agency) by the intended purchaser of the energy crops. In the event of a default, the farmer would be guaranteed a certain minimum amount of income. As there is such a mistrust of contracts at present, there would certainly appear to be a role for Government in improving the institutional structure within which agreements between grower and end-user are determined.

In tackling the known barriers to adoption in this way, the actual supply curve would move closer to the modelled supply curve. As outlined by Sherrington & Moran (2008), perception of financial return from perennial energy crops is not simply a question of anticipated gross margin. Of greater concern to farmers is the security and stability of income from contracts, disruption to cashflow, and reduced farm business flexibility. While the issue of reduced farm business flexibility is difficult to address, concerns over security and stability of income from contracts could be tackled through Government intervention to establish an insurance scheme. In addition, the design of the contracts themselves can help to reduce the disruption to cashflow. The contracts recently offered by Bical demonstrate this in offering deferred payment of 43% of the first two year's costs (Farmers Weekly, 2008).

Directly tackling these known barriers to adoption in this way would lead to uptake of perennial energy crops by farmers at lower gross margins, would help the market to become established, and enable the achievement of carbon reductions at a lower cost than would otherwise have been the case.

23.0 Conclusion

Farm-level modelling suggests that miscanthus, at current prices, should be more widely adopted than is the case. This lends support to the existence of previously identified barriers to adoption (Sherrington et al., 2008; Sherrington & Moran, 2008). SRC willow, on the other hand, remains less financially competitive at present, although the potential for higher prices for heat use is apparent.

Establishment grants are of key importance in encouraging farmers to adopt these crops, as farmers have concerns with the security and stability of income from the available contracts. However, the establishment grants for both miscanthus and SRC willow have been reduced, with greater emphasis now being placed on higher prices available to farmers through contracts. This has meant a drop in the proportion of income that is received upfront and seen by farmers to be secure, and a greater emphasis on deferred income, perceived as less secure. While increasing prices should eventually compensate for the perceived risks facing the individual farmer, this would appear to be an unnecessarily expensive approach when a large number of these risks have already been identified.

An alternative approach, outlined in this paper is for Government directly to address farmer concerns about security and stability of income from contracts through the establishment of an insurance scheme, and for the contracts themselves to be amended to allow for a smoothing of farmer cashflow. This would have the effect of bringing the actual supply response closer to the modelled supply response, and increasing the uptake among UK farmers at lower gross margins. This would allow the achievement of carbon reductions at a lower cost than would otherwise be the case.

24.0 Acknowledgements

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25.0 References

ADAS, 2003. The Mid-Term Evaluation of the England Rural Development Programme (ERDP): Energy Crop Scheme. Available at http://www.defra.gov.uk/erdp/pdfs/midterm/cs_ecs_3.pdf (accessed August 2007)

Arrow, K. J., 1992. Insurance, risk and resource allocation. In G. Dionne & S. E. Harrington, (Eds), Foundations of Insurance Economics, Readings in Economics and Finance. Heubner International Series on Risk, Insurance and Economic Security. Kluwer Academic Publishers Group, Dordrecht, pp.220-229.

Bauen, A. 2008. Personal communication, 16th December 2008.

BWEA, 2008. The Renewables Obligation page on the British Wind Energy Association website www.bwea.com/business/roc.htm

Carbon Finance, 2008. 'EU-ETS Prices bite into Drax's profits', Europe News, 6th August 2008. Available at http://www.carbon-financeonline.com/index.cfm?section=europe&action=view&id=11433 (accessed August 2008)

Carbon Trust, 2005. Biomass sector review for the Carbon Trust, October 2005. Available at http://www.carbontrust.co.uk/publications/publicationdetail?productid=CTC512

(accessed July 2007).

CRL, 2007. Personal communication with Barbara Hilton of Coppice Resources Ltd, August 2007

CRL, 2008. Personal communication with Barbara Hilton of Coppice Resources Ltd, October, 2008.

DARDNI, 2007. Renewable Energy Action Plan, Department of Agriculture and Rural Development Northern Ireland, January 2007. Available at http://www.dardni.gov.uk/renewable-energy-action-plan-2.pdf (accessed July 2007)

DECC, 2009a. The UK Renewable Energy Strategy, Department of Energy & Climate Change, July 2009.

DECC, 2009b. Renewable Heat Incentive webpage. Available at http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/policy/renewable_heat/incentive/incentive.aspx (accessed November 2009).

Defra, 2002. Farm Business Survey 2001/02, sample characteristics, Farm Accounts in England 2002/03.

Defra, 2006. Creating Value from Renewable Materials: A strategy for non-food crops and uses - Two year progress report, Department for Environment, Food and Rural Affairs, November 2006. Available at http://www.defra.gov.uk/farm/crops/industrial/pdf/nfc-progress-0611.pdf (accessed July 2007)

Defra, 2007. UK Biomass Strategy. Department for Environment, Food and Rural Affairs, May 2007.

DTI, 2003. Renewables Innovation Review, Department of Trade and Industry. Available at http://www.dti.gov.uk/files/file22017.pdf (accessed July 2007)

DTI & Defra, 2006. The Government's Response to the Biomass Task Force Report. Available at http://www.berr.gov.uk/files/file28197.pdf (accessed November 2009).

E4Tech, 2009. Biomass Supply Curves for the UK, March 2009. Available at http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/res/res.aspx (accessed November 2009).

European Parliament and Council of the European Union, 2009. Directive of the European Parliament and of the Council on the Promotion of the Use of Energy from Renewable Sources, PE-CONS 3736/08, Brussels, 26 March 2009. Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF (accessed May 2009).

Farmers Guardian, 2008. Renewable energy strategy makes miscanthus 'an attractive alternative', August 15 2008. Available at http://www.farmersguardian.com/story.asp?sectioncode=19&storycode=20678 (accessed August 2008)

Farmers Weekly, 2007. NFU President explains why farmers should welcome the end of set-aside. Available at http://www.fwi.co.uk/Articles/2007/09/27/107146/nfu-president-explains-why-uk-farmers-should-welcome-an-end-to-set-aside.html (accessed September 2008).

Farmers Weekly, 2008. Biofuels Brief: Huge growth for UK biomass. September 3 2008. Available at http://www.fwi.co.uk/Articles/2008/09/03/111947/biofuels-brief-huge-growth-for-uk-biomass.html (accessed September 2008).

Farmers Weekly, 2009a. Liffe prices –Wheat futures prices for 19 November 2009. Available at http://www.fwi.co.uk/StaticPages/liffeprices.htm (accessed November 2009).

Farmers Weekly, 2009b. Long-term view suggests higher world commodity prices. Available at http://www.fwi.co.uk/Articles/2009/01/07/113704/long-term-view-suggests-higher-world-commodity-prices.html (accessed January 2009).

FAO, 2007. Crop prospects and food situation, No. 5, Food and Agriculture Organisation of the United Nations, Rome, October 2007.

Hardaker, J. B., Huirne, R. B. M., Anderson, J. R., 1997. Coping with risk in agriculture. CAB International, Wallingford.

HMSO (2008) Energy Act 2008, Her Majesty's Stationery Office, London. 26th November 2008. Available at http://www.opsi.gov.uk/acts/acts2008/pdf/ukpga_20080032_en.pdf

(accessed May 2009)

Jones, J., 2007. Verification of the calculations, methodology and costings used in determining proposed establishment grant payments under the Energy Crops Scheme - a report for Defra, May 2007.

Meijer, I. S. M., Hekkert, M. P. & Koppenjan, J. F. M., 2007. The influence of perceived uncertainty on entrepreneurial action in emerging renewable energy technology; biomass gasification projects in the Netherlands. Energy Policy 35, 5836-5854.

Meuwissen, M. P. M., Hardaker, J. B., Huirne, R. B. M., Dijkhuizen, A. A., 2000. Sharing risks in agriculture; principles and empirical results. Netherlands Journal of Agricultural Science 49 (2001) 343-356.

Myers, R. J., 1998. The value of ideal contingency markets in agriculture. American Journal of Agricultural Economics 70: 233-242.

Natural England, 2007. Confirmation of the details of the Energy Crops Scheme - Information for applicants. Available at http://www.naturalengland.org.uk/planning/grants-funding/energy-crops/docs/ecs-confirmation.pdf (accessed August 2008).

NFPA, 2009. ROC Auction Prices page on Non Fossil Purchasing Agency website http://www.nfpa.co.uk (accessed August 2009)

Nix, 2007. Farm Management Pocketbook, 38th edition (2008), Imperial College London, Wye Campus

OPSI , 2009. The Renewables Obligation Order 2009. Office of Public Sector Information. Available at http://www.england-legislation.hmso.gov.uk/si/si2009/uksi_20090785_en_1 (accessed November 2009).

Rejda, G. E., 1998. Principles of risk management and insurance. Harper Collins, New York.

RELU, 2009. Policy and Practice Note No. 9, Assessing the social, environmental and economic impacts of increasing rural land use under energy crops, Rural Economy and Land Use Programme, September 2009. Available at http://www.relu.ac.uk/news/policy%20and%20practice%20notes/Karp/Karp.pdf

(accessed November 2009).

Revell, B. and Oglethorpe, D., 2003. Decoupling and UK Agriculture: A whole farm approach. An appraisal of the impact on the livestock sector, commissioned by Defra.

RCEP, 2004. Biomass as a renewable energy source: a limited report by the Royal Commission on Environmental Pollution, London.

SAC, 2002. Farm Management Handbook 2002/2003, Scottish Agricultural College, Edinburgh.

SAC, 2007a. Commercial viability of alternative non food crops and biomass on Scottish Farms - a special study supported under SEERAD Advisory Activity 211, March 2007. Available at http://www.sac.ac.uk/mainrep/pdfs/nonfoodbiomass.pdf

(accessed July 2007).

SAC, 2007b. Farm Management Handbook 2007/2008, Scottish Agricultural College, Edinburgh.

Sherrington, C., Bartley, J. and Moran, D., 2008. Farm-level constraints on the domestic supply of perennial energy crops in the UK. Energy Policy 36, 2504-2512.

Sherrington, C. and Moran, D., 2008. Farmer attitudes and intentions towards the adoption of perennial energy crops in the UK: an application of the Theory of Planned Behaviour. Paper presented at the 16th European Biomass Conference & Exhibition, From Research to Industry & Markets, Feria Valencia, Spain, 2-6 June 2008.

University of Cambridge, 2005. Farm level economic impacts of energy crop production, Final Report to Defra, August 2005.

Valentine, J., Heaton, R., Randerson, P. and Duller, C., 2008. The economics of short-rotation coppice willow in the UK. Paper presented at the 16th European Biomass Conference & Exhibition, From Research to Industry & Markets, Feria Valencia, Spain, 2-6 June 2008.

Welsh Assembly Government, 2007. Personal communication from Vicky Davies, Rural Development Adviser, Technical Services Division, Welsh Assembly Government, Llandrindod Wells.

Chapter 5: An economic assessment of windfarm power generation in Scotland including externalities

The research presented in this chapter has been published as Moran, D. & Sherrington, C., 2007. An economic assessment of windfarm power generation in Scotland including externalities, Energy Policy 35, 2811-2825. While C. Sherrington was in fact the lead author, due to a misunderstanding during submission, the details were incorrectly recorded.

Abstract

This paper uses cost-benefit analysis to assess the economic feasibility of a large scale windfarm project, taking into account positive and negative externalities of generation. The issue of non-use value (i.e. a welfare change among those who will never visit the area and see the windfarm) is addressed with reference to the study by Bergmann et al (2006), which determined a social cost of £19.40 per household for the non-use disamenity associated with a large scale windfarm in Scotland. This paper demonstrates the extent to which this estimate affects the economic feasibility of the project. We find that for all but one of the sixteen scenarios considered, the project returns a positive net present value despite the inclusion of this non-use value, thus suggesting that in these cases the windfarm delivers a net welfare gain to society.

26.0 Introduction

The projected increase in renewable generation capacity in Scotland raises a number of questions about the economic feasibility of renewable energy supplies. In addressing a global external cost, that of climate change, the development of renewables can give rise to other social costs that are predominantly domestic.

Considering the full economic costs, some technologies (e.g. onshore wind power) may be less favoured since they give rise to visual disamenity that some communities feel disproportionately affected by (Simpson 2004). In Scotland, there is an ongoing public debate on the issue of the visual impact of windfarms on the landscape. However, apart from Kennedy (2005), addressing offshore installations on the US eastern sea board, there has so far been no assessment of how such social costs may affect the economic feasibility of specific wind energy projects

Accordingly, this paper presents the results of an economic cost-benefit analysis of a large scale onshore wind energy project in southern Scotland. The aim is to consider the widest social perspective on the project taking both positive and negative externalities into account. The paper is structured as follows. First, we provide some background to the energy strategy in Scotland: a country well positioned to make greater use of renewable energy sources and currently undergoing change in its electricity generation mix. This section will also consider current hurdles to the development of renewable energy projects. Next, the project case study is introduced as a basis for quantifying the range of relevant costs and benefits and assumptions for an economic appraisal. The paper then presents the results of a formal appraisal and sensitivity analysis. The final sections offer discussion and conclusions on research gaps hindering the further development of wind capacity in Scotland and the UK.

26.1 The changing patterns of electricity generation in Scotland

While overall UK energy policy is still reserved to Westminster, following devolution in 1999, substantial areas relating to energy policy are now devolved to the Scottish Executive. These include the promotion of renewable energy and energy efficiency, consents for new electricity generating plant and transmission lines, and land-use planning (Scottish Executive, 2006a). Under Section 36 of the Electricity Act 1989 applications to build onshore windfarms with an installed capacity in excess of 50 MW are made to Scottish Ministers. Below this size, applications are made to the local planning authority, and considered under the Town & Country Planning (Scotland) Act 1997.

This new responsibility comes at a time when the electricity supply industry in Scotland is set, over the next 10-20 years, to undergo a period of rapid transformation. This change is being driven by a range of internal and external factors, (See Macleod *et al* 2006). An outcome of this transition is a move towards an energy mix that gives greater weight to renewables. The Scottish Executive has set two targets for use of renewable power sources. By 2010, 18% of electricity consumed should come from renewable generation, rising to 40% by 2020 (Scottish Executive, 2003). In 2005, the Scottish Ministers re-confirmed the 2020 target, quantifying it as 6 Gigawatts (GW) of installed renewables capacity, confirming that this figure shouldn't be regarded as a cap on development (Scottish Executive, 2005).

A study by Scottish Renewables indicates that by April 2006, 2GW of installed renewable capacity was operating in Scotland. Across 12 months, this capacity should generate around 18% of the anticipated Scottish demand for electricity, thus meeting the 2010 target 3 years ahead of schedule. The study anticipates that by 2010 over 30% of Scotland's electricity could come from renewables, and over half by 2020 (Scottish Renewables, 2006). Onshore wind is expected to play a significant role, with a predicted 2.7GW installed capacity generating 20% of Scotland's demand for electricity in 2010, and 4.2GW installed capacity generating 29% in 2020.

Environmental and economic benefits and costs will accrue to Scotland as a result of these increases in the capacity of onshore wind.

26.2 Possible problems with wind energy

Several arguments are used to oppose windfarms. A commonly cited concern relates to the potential 'intermittency' or more accurately the variability of electricity supply from wind power (ECI, 2005), and the requirement for back up generation capacity. All generators including fossil fuel and nuclear plant need back up, and it is not the case that dedicated plant would have to be constructed to be held in reserve for each specific windfarm that is constructed. However, increasing the proportion of intermittent generation capacity, such as wind, does increase the need for and costs of back up generation, both through system balancing requirements and reliability impacts, i.e. the likelihood that overall capacity will be sufficient to meet peaks in demand (UKERC, 2006).

In Scotland, when production from dispatchable balancing plant is required to make up for an anticipated shortfall in supply, there are a number of options available. These include approximately 1.3GW of hydro-electric plant, 700MW of pumped storage, and 500MW from fast-starting generators and interconnections to England and Northern Ireland (Scottish Executive, 2006b).

A further concern is the potential for intrusive noise both during construction and operation of the wind farm, although recent advances in turbine design have reduced both mechanical and aerodynamic noise. However, the key motivation for anti-windfarm campaigners is opposition to the visual despoliation of valued landscapes (Pasqualetti et al.,2002 ; Burall, 2004). The landscape impacts are exacerbated by the fact that the locations with the highest wind resource are often precisely those exposed upland areas which are valued for their scenic qualities and which are often ecologically sensitive. Opponents not only highlight the scenic impact of the turbines themselves, but also emphasise the visual impacts of the associated construction and upgrades to the electricity transmission system (Warren et al., 2005).

This disquiet about the installation of wind capacity is often expressed in a somewhat unspecific way, combining elements of both use value (residents and visitors who will see - and possibly hear - the windfarm) and non-use value (those who may never visit the area and see the windfarm). In other words, some altered landscapes may affect people's welfare because their use experience is tarnished. For others, the option to visit a landscape free of turbines, or simply the knowledge that a 'pristine' landscape exists is a primary reason for valuing the status quo.

While it is technically possible to quantify these views, there is limited empirical evidence. A study of public perceptions of wind power in Scotland and Ireland suggested an 'inverse NIMBY' syndrome, where those with windfarms in their 'backyard' strongly support the technology (Warren et al., 2005). But a study on non-use value impacts suggests that a large (160MW) onshore wind farm with a considerable landscape impact, results in a welfare loss of £19.40 per household per year (Bergmann et al., 2006). The details and application of this value are discussed later in this study.

26.3 The project

The case study is a proposed wind farm is located in the Upper Clyde Valley in South Lanarkshire, Scotland. The scheme, led by developers Airtricity, proposes the installation of 173 wind turbines each with a generating capacity of 3.6MW, a hub height of 80m and a blade diameter of 90m (total height 125m). It is proposed that one of the turbines will have a viewing platform. Taking 3 years to construct, the project is designed with an operational life of 25 years.

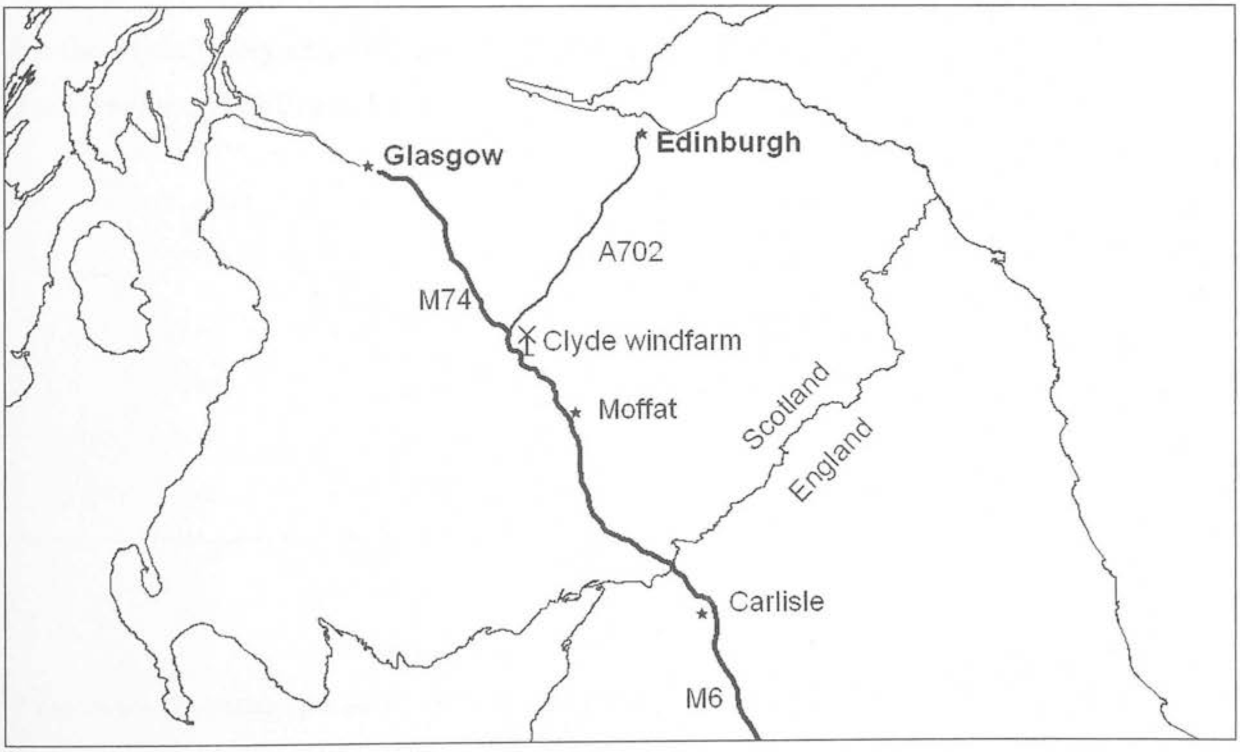

Figure 9: Location of the proposed Clyde windfarm (© Ordnance Survey)

With a total installed capacity of just over 620MW, the developers suggest that the site will generate enough electricity to power up to 440,000 households, and will contribute 0.5 per cent towards the Government's target of 10 per cent of the UK's energy coming from renewable sources by 2010.

The site is divided by the M74 motorway running between Abington, Elvanfoot and Crawford. It occupies approximately 4750 hectares (ha) of farmland, consisting mainly of permanent grassland currently used for sheep grazing, and areas of commercial forestry and heathland.

27.0 Social cost-benefit analysis (CBA)

While it is possible to adopt a private perspective on this project, the presence of wider external costs and the level of public disquiet suggest a more stringent test of economic viability. Social cost-benefit analysis offers a consistent analytical framework for decision-making and is typically designed to help decision-makers allocate scarce resources by determining which option among a competing set should be selected in order to maximize social welfare. This welfare objective encompasses measurable monetary benefits as well as more intangible non-market benefits or public good externalities. Social CBA is typically the perspective adopted by government, and standard guidance is provided by the UK Treasury [11].

The CBA requires the identification of a baseline or status quo scenario, against which the costs and benefits of alternative project interventions are evaluated. The central counterfactual for our analysis below is a gas fired plant of equivalent generating capacity, although the counterfactual of a coal fired plant is also considered.

For the Clyde Valley proposal, the relevant cost and benefit categories to be considered are identified in Table 27

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[11] http://www.hm-treasury.gov.uk/economic_data_and_tools/greenbook/data_greenbook_index.cfm

Costs and benefits of wind energy

Costs	**Benefits**
Market	*Market*
Capital investment	Output revenues
Operation & Maintenance	Avoided fuel costs (gas)
Extra balancing costs to the grid	Avoided GDP losses
Rental cost of land	
Non-market	*Non-market*
Carbon dioxide emissions through manufacture and construction	Avoided emission costs associated with displaced generation
Carbon dioxide emissions through deforestation	
Visual and noise disamenity for residents and visitors (use value)	
Non-use disamenity value	

Table 27: The categories of costs and benefits to be used in the assessment of the Clyde Windfarm

The installed capacity of the Clyde wind farm is taken to be 622.8MW (based on 173 turbines each rated at 3.6MW) as outlined in the Environmental Statement (Land Use Consultants, 2004). Airtricity expects that the Clyde wind farm will have a capacity factor of 38%, that is, the site will operate at the equivalent of full power 38% of the time. The counterfactual gas fired power station, assuming an availability factor of 67% (DTI, 2005), has a capacity of 353MW. The counterfactual coal fired power station, assuming an availability factor of 57.9% (DTI, 2005), has a capacity of 409MW.

Relevant costs and benefits are considered over a time horizon of 25 years. The Treasury *social discount rate* is currently 3.5%. However, the analysis makes a case for alternative discounting assumptions.

27.1 Market costs

27.1.1 Capital investment

The capital cost of the Clyde windfarm is £405 million over a three year period. This is based on a cost of £0.65 million per installed MW for onshore wind (Dale et al., 2004). The value used in the CBA is the difference between this and the cost of constructing an equivalent 353 MW gas fired power station of £159 million, taking the cost per installed MW for gas to be £0.45 million (Dale et al., 2004) The difference in cost between the two is £246 million, which will be the construction cost figure, where gas is the counterfactual, in the analysis to follow.

The 409 MW coal fired power station has a construction cost of £335 million, based on a cost of £0.82 million per MW (Royal Academy of Engineering, 2004). Subtracting from the capital cost of the Clyde windfarm gives a construction cost of £70 million, which will be the figure used, where coal is the counterfactual, in the analysis to follow.

Construction takes three years, and a third of the total cost of construction is attributed to each year. One third of the wind farm will be operational for the second year, and two thirds for the third year.

27.1.2 Operation & Maintenance (O&M)

Annual O&M costs are £9.3 million. This is based on an O&M cost for onshore wind of £15/ (kW y) (Dale et al., 2004). The value used in the CBA is the difference between this and the annual O&M cost of the equivalent 353 MW gas fired power station, taken to be £7 million, based on a figure of £20/ (kW y) (Dale et al., 2004)

[12]. Subtracting the gas fired equivalent O&M costs from the Clyde windfarm O&M costs gives a net annual O&M figure of £2.3 million, to be used where gas is the counterfactual, in the analysis to follow.

For the equivalent 409 MW coal fired power station, the annual O&M cost is £9.8 million, based on a cost of £24/ (kW y) (Royal Academy of Engineering, 2004). Subtracting the coal fired equivalent O&M cost from the Clyde windfarm O&M cost gives a net annual O&M figure of -£0.4 million, to be used where coal is the counterfactual in the analysis to follow.

For the second year of construction, one third of the windfarm is taken to be operational, with two-thirds operational for the third year. The net O&M costs for these years are calculated as above, but adjusted to reflect the installed and operational capacity in the second and third years of construction. Therefore the O&M costs, for gas as the counterfactual, are taken to be £0.75 million (a third of the net annual O&M cost of £2.3 million) in the second year of construction, and £1.5 million (two thirds of £2.3 million) in the third year of construction. O&M costs where coal is the counterfactual are calculated in the same way for these years.

The analysis is simplified by the assumption that the counterfactual generating plant is brought online in stages comparable to that of the windfarm. This is due to the assumption that equivalent revenue from generation (excluding ROCs) is received by the windfarm and the counterfactuals (see 27.2.1) throughout each year of their operational life. In reality, a CCGT plant may be fully operational after two years construction, meaning that at the end of the windfarm's three year construction period, an equal amount of electricity will, in fact, have been generated from both the windfarm and the counterfactual. This would mean that revenue will have been

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[12] The O&M figures from Dale et al. (2004) have been used in preference to those cited in the UK Energy Review (DTI, 2006) (p194, Table B1) which give £44.4/ (kW y) for wind. The Dale et al. (2004) figures are consistent with others, such as Milborrow (2005).

earned from the windfarm one year earlier, but O&M costs will also have been paid earlier. A comparison has demonstrated that altering this simplifying assumption would only make a difference of between 0.03% and 0.12% to the NPV (prior to the application of the non-use value), and therefore the assumption remains.

27.1.3 Extra balancing costs to the grid

As the amount of wind generation on the electricity network increases, and the uncertainties in wind output start to become evident above the normal level of uncertainty in balancing supply and demand, some extra balancing costs will be incurred (Dale et al., 2004).

The estimates to be used in this study are those resulting from the SCAR study (Ilex Energy Consulting and Strbac, G., 2002). These show that the extra balancing costs for wind are 0.1p/kWh at 5.3% penetration, 0.14p/kWh at 7.6%, 0.16p/kWh at 10%, and 0.17p/kWh at 14.2%. A comparison with other estimates featured in The Carbon Trust/DTI's Intermittency Literature Survey & Roadmap (Mott MacDonald, 2003) shows that these values represent the median estimate of balancing costs.

Taking the baseline scenario assumptions as applied in the DTI's Renewables Market Modelling (Oxera, 2004), we obtained the predicted level of wind penetration for each year of the Clyde wind farm's operation. We then applied a figure for the balancing cost for each year based on this forecast. These costs increase from £1.6m for the first full year of operation, to £3.5m for the 25th year.

27.1.4 Rental cost of land

The annual cost to Airtricity of the rent paid to landowners at the Clyde site is £1.7 million.

27.2 Market benefits

27.2.1 Output revenues

From information given by Airtricity, it has been assumed that the output revenues are 5.5p/kWh, excluding the income from Renewables Obligation Certificates (ROCs). However, as the counterfactual investment scenario would also receive similar output revenue, this benefit stream arising from the windfarm will not be included in the analysis. If the project were to be assessed against a 'do nothing' baseline, this would be included as a benefit.

The income from ROCs should not be counted in an economic analysis. ROCs arise from a support mechanism, the Renewables Obligation, designed in part to address the externality of greenhouse gas emissions from conventional fossil fuel generation, but this does not mean that their price accurately reflects the cost of this externality.

The cost of abating a tonne of carbon through the Renewables Obligation is calculated to be in the range of £212 to £447 (Ofgem, 2004). This is significantly higher than the Treasury's social cost of carbon, which will be used in the analysis below. The figure used by the Treasury is £70 per tonne of carbon (in 2000 prices) as an 'illustrative point estimate' of relevant damages, with an upper value of £140 and a lower value of £35 (H.M.Treasury, 2002).

27.2.2 Fuel costs avoided

This is taken to be the cost of gas used for generating electricity in the counterfactual investment scenario, including the gas transportation costs for delivery to the power station. Taking a figure of 35p/therm as the forecast price to be paid by the electricity generators for gas (ILEX, 2006), this translates to a fuel cost (assuming 50% thermal efficiency) of 2.06p/kWh.

Recent wholesale gas prices have, however, been around 80 pence per therm, equating to a cost of 4.7p/kWh. For sensitivity, analysis will be undertaken using the gas price range applied in the UK Government's Energy Review, namely from 21p/therm to 53p/therm (DTI, 2006).

The calculation of avoided fuel costs takes account of anticipated seasonal variations in the load factor of the Clyde wind farm, based on average data from existing wind farms in Ireland with an equivalent load factor (38%), supplied by Airtricity. Greater load factors are achieved during the windier winter months, coinciding with periods when gas prices are typically higher than average. Monthly gas price projections (Ilex, 2005) shows a circa 5 pence range in price over the year when the mean price is 35p/therm. Converting this to an approximate percentage change from the mean per month enabled the calculation of monthly prices. Multiplying these monthly prices by the monthly load factor increases the annual avoided cost of gas by 2.6% compared with using one price and the average annual load factor. The resulting avoided fuel costs for each year of full operation of the windfarm are £43.8 million.

Fuel is a high risk cost stream, not simply because of the fluctuation in fuel prices over time, but because the cost of fuel co-varies negatively with returns on other assets; i.e. when fuel prices increase, returns to other assets decline (Awerbuch, 1995). This risk differential motivates arguments for an alternative discounting approach to these streams. In this case a rate is therefore applied to the avoided fuel cost stream using the Capital Asset Pricing Model (CAPM) approach (Awerbuch 2003a). This takes into account the extent to which the fuel cost stream co-varies systematically with the returns that would be obtained on a broadly diversified portfolio of assets.

The mathematical measure of systematic risk, β (beta), is the expected percentage variation in the cost stream when returns to a broadly diversified portfolio change by 1%. A beta of -0.02 for gas is used by Awerbuch (2006) to estimate a market (pre-tax) discount rate of 4.3% for gas. By netting out personal and corporate taxes, Awerbuch derives a Social Rate of Time Preference (SRTP) value of 1.7% nominal. Assuming a 3% rate of inflation, this gives a real discount rate of –1.1% to be applied to this cost stream.

For the coal fired counterfactual, the cost of coal is taken to be £30/tonne, which gives a fuel cost of 1.16p/kWh (Royal Academy of Engineering, 2004). Using the CAPM approach, a real discount rate of -1.3% is applied to this cost stream.

27.2.3 Avoided GDP losses

There is empirical evidence from a growing body of academic literature that oil price increases and volatility dampen macroeconomic growth by raising inflation and unemployment and by depressing the value of financial and other assets. These losses are in the order of 0.5% of GDP for a 10% oil price increase (Awerbuch, 2005a). By displacing gas and oil, increased use of renewable energy can help nations avoid these macroeconomic losses. This avoided GDP loss is attributable to renewable energy investments.

It is estimated that this benefit is worth $200/kW (£114/kW) for wind energy installations, based on a capacity factor of 23% (Awerbuch, 2005a). For the purposes of this report, this figure has been increased to represent the 38% capacity factor of the Clyde project, giving £188/kW, and multiplied by the installed capacity (622.8 MW) to give a figure of £117.2 million. This is a one-off benefit, attributed to 2009, the first full year of the wind farm's operation.

27.3 Non-market benefits

27.3.1 Carbon emissions avoided

Electricity generated by wind power avoids emissions of carbon dioxide through the displacement of conventional fossil-fuelled generation. To quantify this benefit, it is necessary to estimate avoided emissions. This depends on the amount of electricity produced and electricity generating technology displaced. A monetary value can then be placed on these avoided costs using a shadow value of carbon.

27.3.1.1 Amount of electricity produced by the Clyde windfarm

Airtricity expect that the Clyde wind farm will have a capacity factor of 38%, that is, the site will operate at the equivalent of full power 38% of the time. The amount of electricity produced by the wind farm can be estimated by:

Installed capacity (MW) x Capacity factor (%) x Number of hours in a year

Therefore electricity produced = 622.8MW x 0.38 x 8760 = 2073 GWh

27.3.1.2 Generating sources displaced

In Scotland the immediate effect of a windfarm may be to displace the generation of electricity from hydropower. Scotland has approximately 1.3GW of hydro-electric plant and 700MW of pumped storage (Scottish Executive, 2006b), and in an average year, hydro generates 12% of Scotland's electricity needs (Scottish Renewables, 2006). However, the displaced hydro may then displace coal or gas generation at a later date. It is therefore assumed that wind displaces fossil fuel, either immediately or via hydro. The three options to be considered for the generation sources displaced by the Clyde windfarm in this analysis are now discussed.

- Option 1 – Wind displaces coal fired generation

It is argued by the British Wind Energy Association (BWEA), that in both the short and long term, wind saves on emissions from modern coal-fired plant (BWEA, 2005). This is demonstrated in data published by The National Grid Company which describes the make-up of plant on the system at various times (National Grid Transco, 2004). The nuclear and Combined Cycle Gas Turbine (CCGT) plant operates continuously throughout the day and the output of the coal plant is varied to meet demand. It is noted that the output from coal plant will not change in response to every fluctuation in wind output. It will be adjusted in response to the aggregated change in demand, of which wind contributes only a small proportion.

In the longer term, as the older coal plants become uneconomic, or surplus to requirements due to the construction of new gas or renewables, they are shut down.

Average emissions from coal-fired plant are taken to be 0.86kg CO_2/ kWh, thus this is the CO_2 saving associated with the generation of electricity from wind if it displaces coal.

- Option 2 – Wind displaces the typical grid mix

The carbon intensity of the grid, based on the average grid mix is 0.43kg CO_2/kWh (Carbon Trust, 2006). This emissions figure is taken from Defra's 'Environmental Reporting Guidelines for Company Reporting on Greenhouse Gas Emissions', and is used for the purposes of environmental reporting, the UK Emissions Trading Scheme, and the Climate Change Levy agreements.

This figure for electricity was calculated in 1999 based on the projected fuel mix for the grid 1998-2000. Actual figures may differ from the projections, but it is intended to be used by Defra as a constant value for environmental reporting until the year 2010 (Defra, 2006).

It is argued that this figure does not reflect reality, suggesting as it does that wind will displace coal, gas and nuclear in equal measure. Nuclear, for example, being baseload plant, and is completely unaffected in its daily operations by the addition of new generating plant (BWEA, 2005).

- Option 3 – Wind displaces Gas

In its Regulatory Impact Assessment for the Renewables Obligation, the DTI assumed that the main impact of extra renewables is to reduce investment in new gas combined cycle stations and that each TWh would produce 2.5mtC. This is equivalent to a figure of 0.38kg/CO_2/kWh (DTI,2002).

This contradicts an earlier DTI study, which states that renewables displacing combined cycle gas turbines 'is unlikely in practice at present, because this high efficiency (where efficiency refers to the amount of electricity generated per unit of CO_2 emitted), fossil fuel technology is being increasingly deployed in the UK' (DTI, 1999).

The assumption that wind displaces gas is supported by the Royal Academy of Engineering, (2004) with open-cycle gas turbines (OCGT) identified as the most appropriate technology if talking about new build rather than just using existing plant. It is also the assumption made by Dale et al (2004).

The carbon dioxide emissions avoided under the three options are as follows:

Option 1 – Displacing Coal	1.8 million tonnes CO_2
Option 2 – Displacing Typical Grid Mix	0.9 million tonnes CO_2
Option 3 – Displacing Gas	0.8 million tonnes CO_2

Of these, wind displacing gas will be the central assumption of the study, with wind displacing coal used for sensitivity analysis. Wind displacing the typical grid mix is not considered further.

27.3.2 Placing a value on the avoided emissions

The technique used in this study to estimate the value of the avoided emissions is that used by the UK Treasury to assess the societal cost of emissions of carbon dioxide.

H.M. Treasury (2002) reviewed all available studies on the cost of the physical impacts of climate change. The most sophisticated of the published studies reviewed produced a marginal damage estimate of £70/tC (2000 prices) for carbon emissions in 2000. This increases by approximately £1 per tonne in each subsequent year to account for increasing damage costs over time.

This figure is subject to significant uncertainty and excludes consideration of the probability of 'climate catastrophes' and socially contingent impacts of climate change that could, potentially increase the size of damages considerably.[13]

As such, the Treasury settle on a figure of £70 per tonne of carbon (in 2000 prices) as an 'illustrative point estimate' of relevant damages, using an upper value of £140 and a lower value of £35. This increases by approximately £1 per tonne in each subsequent year to account for increasing damage costs over time (H.M.Treasury, 2002).

These three values will be used to represent Low, Medium and High values of carbon. One tonne of carbon is equal to 3.67 tonnes of CO_2, giving the following figures.

Low	£35/tonne carbon or £9.50 /tonne CO_2
Medium	£70/tonne carbon or £19.10/tonne CO_2
High	£140/tonne carbon or £38.15/tonne CO_2

A GDP deflator (H.M. Treasury, 2006) has been used to convert the values into 2006 prices. Thus the 2006 value of a tonne of carbon is £87, which equates to a value of £24/€35 per tonne of carbon dioxide.

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[13] Government guidance has since been updated, with the approach based on the social cost of carbon now superseded by use of the shadow price of carbon (DECC, 2009). As electricity generated for the grid falls within the EU Emissions Trading Scheme, the lower 'traded' price of carbon would be used in this evaluation to value the avoided emissions from either coal or gas fired plant. This would have the effect of lowering the monetised benefits associated with carbon savings attributable to the windfarm. However, for consistency with the published paper, the original values relating to the social cost of carbon are used in this chapter.

The annual value of avoided emissions, using the central value of carbon increases from £19.5million in the first year of full operation, to £25.4 million in the 25th year of operation.

27.4 Non-market costs

27.4.1 Carbon dioxide released during manufacture and construction

This figure is based upon a Life Cycle Analysis study showing that onshore windfarms pay back the carbon dioxide released during their manufacture and construction within 0.29 years of operation (Schleisner, 1999).

The value used is 0.29 of a year's worth of avoided carbon dioxide, based on the same conversion factor used for the main avoided emissions calculation. This is then multiplied by the same value of carbon that has been used to value the avoided emissions using the social cost of carbon methodology. It is then divided equally over the three years of construction. Using the central value of carbon, this cost is £1.8million for each year of construction.

It is important to note that no similar calculation has been undertaken for the counterfactual investment option of a gas-fired power station. This follows the ExternE (European Commission, 1999) methodology whereby the fossil fuel cycle only takes into account emissions from operation, as these dwarf the emissions from construction. For a wind farm, conversely, the only significant emissions are from manufacture and construction.

27.4.2 Carbon dioxide released through deforestation

1070ha of commercial plantation will be removed as part of the site preparation for the windfarm. In the absence of the proposed windfarm, this same area would be deforested, but the felling would take place over the period to 2098 rather than to 2008.

However, there would be no resulting net increase in CO_2 emissions. The use of these trees meets demand that would otherwise be met by the felling of alternative trees. Or if the trees were used for co-firing, they might well displace coal, thus reducing net CO_2 emissions.

27.4.3 Visual and noise disamenity for residents and visitors

The principal external costs of windfarms are visual impact and noise. Both forms of impact can be assessed using market and non-market benefits assessment information. However the application of these methods to specific wind installations is minimal and this complicates our analysis.

In this section we establish a method to value the impacts to residents and visitors based on transferring and calibrating existing landscape willingness to pay (WTP)/value information. Our analysis will focus on visual impact that reduces these landscape values. The Environmental Statement has determined that in contrast to the visual impact, the noise impact of the operational windfarm is not likely to be significant.

Damages to residents can be measured in two ways. A revealed preference approach can be used to consider the impact of wind turbines on house price values for properties in the vicinity. This "hedonic" pricing approach has been used to consider the impacts of pylons and cables in the UK (Atkinson et al., 2005). The main difference with pylons and cables is the presence of a potential health impact, which can be valued highly because of a so–called "dread" factor. This confounding effect means that using revealed data from pylon studies may produce unreliable results when transferred to wind installations.

For the purposes of this analysis and in the absence of site-specific evidence, we need to make assumptions about how any benefit information can be derived by benefits transfer.

27.4.3.1 Landscape amenity valuation

The method proposed to value visual impact on landscape from wind turbines considers damaged use values among residents and visitors.

The use damage estimate considers the nature of intrusion (pre and post construction), exposure to intrusion (number of residents and visitors per year), and unit landscape values (WTP values for the actual intrusion category or alternatively WTP for landscape types).

A range of landscape values can be found in studies by Garrod and Willis (1997); Garrod and Willis (1995); Hanley *et al* (1998); Price (1993) and Hamilton and Schwann (1995).

Typically the available studies relate to valuation of amenity of areas under agri-environmental schemes. Such areas will have higher amenity value than the Clyde location and we recognise that statutory duties preclude resource development in these areas. In the case of the Clyde site, recreational shooting under the control of landowners takes place, but use of the site for informal recreation such as walking/cycling is considered to be limited (Land Use Consultants, 2004). The Southern Upland Way does, however, pass near the southern boundary of the site, with an estimated 5212 visitors to the two sections of the route closest to the site (Land Use Consultants, 2004). In any case, choosing these WTP values will likely overstate the damage estimate here.

Cost calculations are detailed in the following steps:

Step 1: Establish and measure landscape impact

These stages describe how we determine the monetary equivalent of a landscape impact caused by turbines. The method applies a benefits transfer approach. In other words we do not undertake any primary valuation studies to elicit willingness to pay, but attempt to adjust existing amenity value information.

We suggest site degradation is defined by an ordinal impact scale (see Table 28), which can be associated with WTP reduction factors. In other words, the willingness to pay or value of a pristine landscape is reduced successively by higher levels of intrusion. The estimates in the table are arbitrary but given time these intrusion classes and factors could be elicited as part of an on-site survey conducted among a sample of visitors and residents.

Landscape Intrusion Scale	WTP reduction factor	
Unsightly	80%	implies factor WTP*0.2
Undistinguished	50%	implies factor WTP*0.5
Slight intrusion	40%	implies factor WTP*0.6
Distinguished/attractive	30%	implies factor WTP*0.7
Superb/excellent	10%	implies factor WTP*0.9
Spectacular/exceptional	0	implies factor WTP*1

Table 28: Landscape intrusion scale adapted from Price (1993)

Step 2: Establish willingness to pay

Mean landscape WTP is a value transferred from a valuation study covering resident and visitor valuation of a similar landscape type. Table 29 provides a range of transfer values from various landscape studies. The landscape types referenced by these values correspond to different landscape types across the UK. The study by Bullock and Kay (1996) provides a value that can be transferred to provide an approximate value in the Clyde case.

Step 3: Specify exposure

Exposure to visual impact pre and post construction is defined as the number of residents and visitors likely to experience the landscape impact. While there may often be reduced visibility due to rain or mist, we do not reduce the values to take account of this. We suggest that apart from detriment to outstanding beauty spots, visitation rates can be assumed constant for years following construction.

Study	Country	WTP residents (£)	WTP visitors (£)	General public (£)	Base year
Hanley et al. (1997) - Breadalbane ESA	UK	31.43	73.00	22.02	1995
Hanley et al. (1997) – Machair ESA	UK	13.66		13.37	1995
Garrod & Willis (1993) – South Downs ESA	UK	27.52	19.47	1.98	1992
Garrod & Willis (1993) – Somerset Levels ESA	UK	17.53	11.84	2.45	1992
Gourlay et al. (1996) – Loch Lomond ESA	UK	20.60	1.98 per visit		
Gourlay et al. (1996) – Stewarty ESA	UK	13.00	2.53 per visit		
Bullock & Kay (1996) – Southern Uplands ESA	UK	69.00		83.00	1995
Garrod et al. (1995) – WTP to maintain ESA scheme in England	UK			36.35	1994

Table 29: Environmentally Sensitive Area landscape values (WTP, £/hhld/yr)

We have used a Geographical Information System (GIS) to accurately establish the number of residents (and number of households) within the Zone of Visual Influence (ZVI) as outlined in the Environmental Statement. The outer limit of the ZVI is 35km from the perimeter of the site. Within this area there are just over 220,000 residents (just under 98,000 households).

The Environmental Statement contains GIS output illustrating the areas within the ZVI from which certain numbers of turbine tips can be seen. The numbers are grouped into ranges, such as 1-30, 31-60 etc. However, there is no attendant information as to how many people are resident in these areas. We obtained the source data for this illustration, and using a GIS, overlaid it with unit postcode data which contains population and household numbers for each individual postcode. This information was then grouped by distance from the perimeter of the site, in concentric bands of 5km width. The results are shown in Table 30 and Table 31.

Table 30 shows the number of households, while Table 31 shows the number of residents.

It is clear from both tables that despite the fact that the windfarm contains 173 turbines, it will not be possible for all turbines to be viewed simultaneously from any residence within 35kms of the perimeter. There are nine households from which 116-145 turbine tips will be visible, and a further nine from which 90-115 tips will be visible, and these are located between 20 and 25 kilometres from the site boundary.

Exposure for residents will vary both with the number of turbine tips visible, and the distance from the perimeter of the site. We will apply a 'distance decay' function and also calibrate the impact depending on the number of turbine tips visible.

	Number of turbine tips visible					
Distance from site boundary (km)	1-30	31-60	61-90	91-115	116-145	146-173
0 to 5	255	122	98	0	0	0
5 to 10	446	62	0	0	0	0
10 to 15	1653	43	0	0	0	0
15 to 20	3192	188	29	0	0	0
20 to 25	2790	323	9	9	9	0
25 to 30	5341	1066	11	0	0	0
30 to 35	13167	487	1652	0	0	0

Table 30: The number of households in areas from which different numbers of turbine tips are visible, grouped by distance from the site perimeter

	Number of turbine tips visible					
	1-30	31-60	61-90	91-115	116-145	146-173
Distance from site boundary (km)						
0 to 5	638	307	246	0	0	0
5 to 10	1011	134	0	0	0	0
10 to 15	3610	99	0	0	0	0
15 to 20	7193	433	61	0	0	0
20 to 25	6904	784	22	22	22	0
25 to 30	12751	2549	22	0	0	0
30 to 35	29804	1263	3469	0	0	0

Table 31: The number of residents in areas from which different numbers of turbine tips are visible, grouped by distance from the site perimeter

For visitors we will use the figure supplied in the Environmental Statement for the numbers using relevant sections of the Southern Upland Way. It is estimated that annually there are 5212 visitors to the two sections of the Southern Upland Way closest to the site (Land Use Consultants, 2004).

Step 4: Establish change in landscape value

Damage = Site degradation (%) x Exposure to visual damage x Mean landscape WTP

This should be calculated for each class of residents and visitors who suffer exposure, and summed to give the total damage.

27.4.3.2 Application

Assume the Clyde wind farm is constructed in a landscape similar to the Environmentally Sensitive Areas considered by Bullock and Kay (1997). The latter study provides a residents' willingness to pay value for landscape preservation that we assume to be the value placed on a landscape without wind farms. This is damaged by turbines, and we need to determine the extent of this damage. The same study does not provide a value for visitors, and so we transfer the benefit estimate shown for the South Downs ESA (Garrod and Willis 1993). Consider the value change applies to the 71,344 residents who can see at least 1 turbine tip from within the 35km ZVI and the estimated 5212 visitors per annum to the two sections of the Southern Upland Way closest to the site (Land Use Consultants, 2004).

- Visitors

Assume around 2500 suffer "unsightly" intrusion, and 2712 are in the "undistinguished" impact category. From Table 28 implied impact scores are 80 per cent and 50 per cent of WTP values respectively. From Table 29 non-resident WTP £19.47/year.

Visitor WTP reduction "unsightly" from Table 28 = (0.2 x £19.47) = £ 3.80

Welfare reduction per visitor per year = £19.47 - £3.80 =£15.67

Visitor WTP reduction "undistinguished" = (0.5 x £19.47) = £9.70

Welfare reduction per visitor per year = £19.47 - £9.70 = £9.77

Visitor weighted loss = (2500 x £15.67) + (2712 x £9.77) = £65671.2 per year

Note that this assumes constant visitor numbers, but these may also change in the post construction era. They may well increase, as visitors may be attracted to the viewing platform. It is likely that such visitors, through self-selection, might have a positive view of the wind farm. Moreover, as discussed below, we may also wish to assume a factor for a changing social perception of wind energy in the environment. This may vary between residents and visitors. However, for the time being, we incorporate this estimate into our spreadsheet.

- Residents

The number of residents in areas from which different numbers of turbine tips are potentially visible was indicated in Table 31. These residents are grouped by distance from the site perimeter in 5km intervals.

Following the landscape intrusion scale outlined in Table 28, those who can view 61-90 turbine tips are deemed to suffer "unsightly" intrusion. This gives an implied impact score of 80 per cent of WTP values, taken from Table 29 to be £69 per resident per year. This and other impact scores are shown in Table 32.

No of turbine tips visible	Impact Score	Welfare loss per resident/year
1-30	70%	£48.30
31-60	75%	£51.75
61-90	80%	£55.20
91-115	85%	£58.65
116-145	90%	£62.10
146-173	N/A	N/A

Table 32: Impact scores and related annual welfare loss per resident based on number of turbine tips visible, taking a residents WTP of £69 from Bullock and Kay (1997)

The reduced visual intrusion through increased distance from the site perimeter is accounted for by adjusting the weighting for each five kilometre grouping. Those residents within 0-5km of the site perimeter are attributed the full value based on the visibility impact scores. The weightings for this and each subsequent distance band are shown in Table 7. These weighting estimates are arbitrary but given time they could be elicited as part of an on-site survey conducted among a sample of residents.

Distance from site perimeter (km)	Weighting
0 – 5	100%
5 – 10	75%
10 – 15	50%
15 - 20	25%
20 – 25	15%
25 - 30	10%
30 - 35	5%

Table 33: Weightings given to residents' WTP value based on distance from perimeter of site

As an example, the visual disamenity for the 134 residents who can see 31-60 turbine tips and live 5-10kms from the site is calculated as follows:

*The 134 residents have a visual impact score of 75%, which means an individual annual welfare loss of £51.75 (£69*0.75). Cumulatively this is £6934.50. This is then weighted by distance, so 75% of this value is taken, giving a weighted cumulative annual welfare loss of £5200.87.*

This process is repeated for all the residents in each visibility and distance grouping, giving a total welfare loss of £501,533.41 per year. Combining this with the welfare loss to visitors gives an overall welfare loss due to visual disamenity of £567,000 per year.

27.4.3.3 Changing perceptions of wind energy in the environment

Two elements need to be mentioned at this point. The first is that anecdotal evidence appears to suggest that residents become accustomed to windfarms, which engender a sense of civic pride in installations that are effectively agents of environmental good. No studies have assessed this element in terms of a monetary valuation, but in traditional economic terms, it would suggest that the value of any disamenity impact should fall through time rather than being an invariant cost in the CBA. Local part-ownership of a windfarm may also improve perception among residents (Toke, 2005), along with local employment or donations for community facilities through planning gain from the development.

The second factor is that visual intrusion is essentially reversible. It is unclear whether the transferred WTP values we might use here are for changes that were portrayed as irreversible. This has to make a difference.

27.4.4 Non-use disamenity

The visual impact of a windfarm is essentially site specific and varies according to the existing landscape, and the level to which residents and visitors are "exposed" to the impact. A complicating factor is added by the non-use disamenity of landscape change. In other words, beyond local impacts, wider populations of the UK may have preferences over the impacts of installations, irrespective of whether they actually experience them directly. They are simply damaged in a passive way by the knowledge of installations influencing landscape form.

Interest in the concept and measurement of non-use value is not new and there has been considerable theoretical and methodological debate in the area of environmental economics concerned with nature and heritage conservation. This literature has developed the basis for using stated preference methods (contingent valuation and choice experiments) to determine the economic or monetary value of non-use impacts. This is a development that is now recognised as a legitimate process in public appraisal (e.g. the Treasury Green Book).

The existence of non-use or passive value is intuitive for celebrated and iconic landscapes, but not necessarily so for all landscapes. It is however, difficult to argue that these values do not exist and the existence of empirical estimates does give substance to a popular debate that is largely uninformed by data.

Unfortunately the stated preference literature does not provide general rules to help us determine the size of non-use value nor how values might change in relation to different landscapes or the proximity of the individual preference holder to the environmental attribute in question. To deal with this, our analysis can either attempt to transfer existing estimates from previous studies or determine these impacts on a case-by-case basis. Accounting for this impact is more complex than the use (residents and visitor) impacts, which can at least be calibrated by a fixed number of "damaged" individuals, i.e. a range can be placed by measuring residents in proximity to installations and visitor numbers to the vicinity.

There are several existing valuation studies addressing the impact of wind energy (Alvarez-Farizo and Hanley 2002; Ek 2002; Navrud 2004) These studies suggest that non-market impacts can be as high as £17 per household per year. A study that explicitly considers the nature of visual landscape impact in Scotland has been conducted by Bergmann et al. (2006). But even this study does not actually show specific installations in a landscape context. Instead, the study uses stated preferences to consider the impacts of infrastructure (visual, wildlife and air pollution) in a somewhat abstract way and the values that emerge from the choice experiment are not site or project specific. In essence, the authors target the non-use category of respondents mentioned above, and effectively the values they derive can be argued to apply to the whole population. These values are then assigned to what they consider to be typical infrastructure intrusions, which in their onshore wind case amount to a 160 MW wind farm. There are many possible criticisms of this study. The main criticism is that respondents to the survey never actually get to see a case of wind farm intrusion on which to base their responses. Moreover the distinctions between low, moderate and high landscape impacts are unclear and some of the econometric models suggest that impacts are actually statistically insignificant, thus rendering the results of limited value.

The upper limit of damages suggested in the Bergmann study is that the average Scottish household suffers an annual welfare loss of £19.40 from the major landscape impact. The study suggests that this impact is associated with a 'large' windfarm (160 MW - 80 turbines). The 622MW Clyde project, has more than double the number of turbines (173) and almost four times the installed capacity of this hypothetical example. If this is truly an annual welfare loss in the presence of the Clyde proposal, then the aggregate value (if multiplied by the 2.1 million Scottish households) is £40.74 million per year. At this point, and in the absence of primary research, we suggest that this is the upper limit of the non-use damage attributable to the Clyde installation, even though the true estimate is likely to be lower.

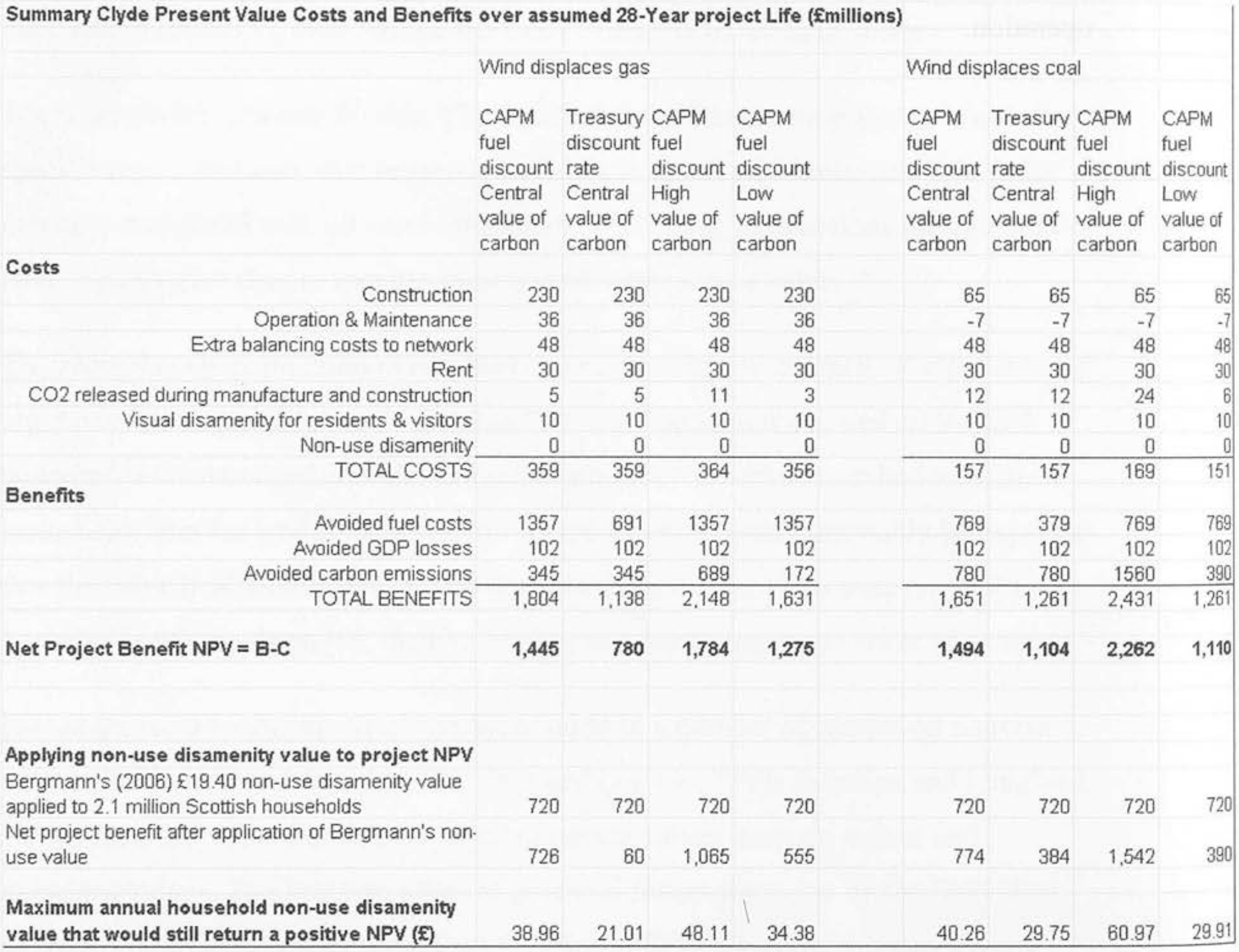
There are several reasons for this. The first is that the Bergmann estimate is not site specific and in fact may lead respondents (in their stated preference study) to infer damages associated with all wind installations, including assumptions about iconic landscapes, rather than at specific locations of lesser scenic value.

The second is the population over which this value might be applied. For the sake of argument in determining our "worst case", it could potentially be that all Scottish households are damaged and that the value of £19.40 should be ascribed to each household. But for landscapes of lesser scenic value, it could reasonably be expected that the value held will diminish with distance from the site. This suggests that fewer households will be damaged, thereby leading to a lower aggregate value of damages.

Indeed the distance decay effect has been found in a number of studies on non-use values (Sutherland and Walsh, 1985; Pate and Loomis, 1997; Bateman and Langford, 1997). Non-use value can be comprised of option values, bequest values and existence values. The first two relate to potential future direct use by the individual or their offspring respectively, and are therefore still likely to show some (inverse) relationship with measures of physical distance between the public and the resource (van der Horst, 2007). Existence value is derived from knowledge or awareness of the existence of a specific place. If the existence value of a location is seen as dependent on people's knowledge of this location (e.g. Price, 2000), then it is logical to expect that existence values can also be subject to some form of distance decay (step-wise if not gradual), as, for example, a large proportion of the media is dedicated to more local coverage (van der Horst, 2007).Further reasons for adjusting the extent of the Bergmann estimate can be justified with reference to the nature of the respondent sample used in the study (i.e. the balance between rural and urban respondents). Furthermore, the possibility that opposition to wind installations might diminish through time with increasing acceptability of the technology would mitigate against using the Bergmann estimate as an invariant annual value. However, we do not attempt to adjust the value, nor do we introduce alternative estimates for non-use value at this point. The non-use disamenity value of £40.74 million will therefore be attributed to each year of the project's construction and operation.

28.0 Results and sensitivity analysis

All cost and benefit streams are discounted at the UK Treasury's social discount rate of 3.5%, except for the avoided fuel cost stream. In most scenarios this is discounted at a rate of -1.1% for gas, and -1.3% for coal, a figure obtained by using the Capital Asset Pricing Model (CAPM) approach (Awerbuch, 2006). For comparison there are two scenarios, one each for coal and gas, where the fuel cost stream is discounted at the Treasury rate.



Summary Clyde Present Value Costs and Benefits over assumed 28-Year project Life (£millions)

	Wind displaces gas				Wind displaces coal			
	CAPM fuel discount Central value of carbon	Treasury discount rate Central value of carbon	CAPM fuel discount High value of carbon	CAPM fuel discount Low value of carbon	CAPM fuel discount Central value of carbon	Treasury discount rate Central value of carbon	CAPM fuel discount High value of carbon	CAPM fuel discount Low value of carbon
Costs								
Construction	230	230	230	230	65	65	65	65
Operation & Maintenance	36	36	36	36	-7	-7	-7	-7
Extra balancing costs to network	48	48	48	48	48	48	48	48
Rent	30	30	30	30	30	30	30	30
CO2 released during manufacture and construction	5	5	11	3	12	12	24	6
Visual disamenity for residents & visitors	10	10	10	10	10	10	10	10
Non-use disamenity	0	0	0	0	0	0	0	0
TOTAL COSTS	359	359	364	356	157	157	169	151
Benefits								
Avoided fuel costs	1357	691	1357	1357	769	379	769	769
Avoided GDP losses	102	102	102	102	102	102	102	102
Avoided carbon emissions	345	345	689	172	780	780	1560	390
TOTAL BENEFITS	1,804	1,138	2,148	1,631	1,651	1,261	2,431	1,261
Net Project Benefit NPV = B-C	**1,445**	**780**	**1,784**	**1,275**	**1,494**	**1,104**	**2,262**	**1,110**
Applying non-use disamenity value to project NPV								
Bergmann's (2006) £19.40 non-use disamenity value applied to 2.1 million Scottish households	720	720	720	720	720	720	720	720
Net project benefit after application of Bergmann's non-use value	726	60	1,065	555	774	384	1,542	390
Maximum annual household non-use disamenity value that would still return a positive NPV (£)	38.96	21.01	48.11	34.38	40.26	29.75	60.97	29.91

Table 34: Summary Clyde present value costs and benefits

From Table 34 it can be seen that for the eight main scenarios considered, the project delivers a positive net present value ranging from £780 million to £2.3 billion before accounting for the non-use disamenity impact. Applying the non-use disamenity present value of £720 million (based on a non-use welfare loss of £19.40 for each of the 2.1 million Scottish households (Bergmann et al., 2006), the project still returns a positive net present value for each scenario. This ranges from £60 million to £1.5 billion.

The final row indicates the maximum annual household non-use welfare loss, for each of the 2.1 million Scottish households, that could be sustained while still returning a positive net present value under each scenario. That is to say, the project would still deliver a welfare gain to Scotland even if this non-use disamenity value were held. This figure ranges from £21.01 up to £60.97.

It is of greatest interest to note the sensitivity of these results to the number of households to which the non-use value of £19.40 is applied. If the figure were applied to 2.28 million rather than 2.1 million households, the net present value for the gas scenario where the fuel is discounted at the Treasury rate would be negative.

28.1 Sensitivity to gas prices

It can be seen from Table 34 that in all but one of the scenarios (wind displaces gas, with a low value of carbon), the benefits arising from avoided GDP losses and carbon savings are greater than the sum of the costs (excluding the non-use disamenity value). That is to say, in an analysis that did not take account of the non-use disamenity value, even if the avoided costs of gas were to drop to zero, the benefits would outweigh the costs in most scenarios. Thus it is the application of the non-use value that renders the avoided gas costs so significant for the project NPV.

The results in Table 34 refer to a gas price of 35p/therm. Table 35 shows the sensitivity to gas prices, using a high price of 52p/therm, and a low price of 21p/therm, as used in the UK Government's Energy Review (DTI, 2006).

Sensitivity to gas prices	CAPM fuel discount	Treasury discount rate	CAPM fuel discount	CAPM fuel discount
	Central value of carbon	Central value of carbon	High value of carbon	Low value of carbon
Gas price 21p/therm				
Project NPV before non-use disamenity	**903**	**503**	**1,242**	**733**
Applying non-use disamenity value to project NPV				
Bergmann's (2006) £19.40 non-use disamenity value applied to 2.1 million Scottish households	720	720	720	720
Net project benefit after application of Bergmann's non-use value	183	-217	522	13
Maximum household non-use disamenity value that would still return a positive NPV (£)	24.33	13.56	33.47	19.75
Gas price 52p/therm				
Project NPV before non-use disamenity	**2,105**	**1,115**	**2,444**	**1,935**
Applying non-use disamenity value to project NPV				
Bergmann's (2006) £19.40 non-use disamenity value applied to 2.1 million Scottish households	720	720	720	720
Net project benefit after application of Bergmann's non-use value	1,424	1,135	2,483	1,254
Maximum household non-use disamenity value that would still return a positive NPV (£)	57.78	30.6	66.92	53.2

Table 35: Sensitivity to gas prices

In all but one of the scenarios in Table 35, the project still returns a positive NPV even with the inclusion of the £19.40 non-use figure applied to 2.1 million households. In the one scenario where a negative NPV is returned, the maximum annual household welfare loss, for each of the 2.1 million Scottish households, that could be sustained while still returning a positive net present value would be £13.56.

29.0 Discussion

The significance of the non-use value is clear from Table 8. It is roughly twice the size of all the other cost categories put together for the gas counterfactual, and over four times the total of all other costs for the coal counterfactual.

As mentioned above, the cumulative non-use value is based on the arbitrary choice of applying the £19.40 to all Scottish households, of which there happen to be 2.1 million. Under the gas scenario where the fuel is discounted at the Treasury rate, the net present value is negative when the non-use figure is applied to 2.28 million households, a Scottish households figure that would arise if the Scottish/English border happened to be drawn 30 miles further south.

This raises an important issue for the application of non-use value – the placing of bounds. Is an administrative boundary really appropriate? Would a windfarm that is closer to Carlisle than it is to Perth not have a greater non-use effect on those immediately over the border in England? If a similar windfarm were built in England should the non-use value be applied to all 21million households, or is there a distance decay function that can more readily capture the non-use disamenity value of a specific installation?

There is also the issue of how this non-use value might vary through time. With an increasing number of windfarms being developed, would the non-use disamenity value associated with each marginal installation increase or decline? If tackling climate change becomes a far more significant priority as far as the public are concerned, would there be a greater acceptance of wind installation, marked by a declining non-use disamenity value?

However, of greater practical interest is the use of landscape valuation techniques to place a monetary figure on the costs associated with the visual impact of specific installations for residents and visitors, i.e. the changes in use values for those who will directly experience the windfarm. Applying a consistent approach to quantifying the visual impact in each instance, would arguably represent a significant step forward in the process of assessment, enabling different schemes to be compared using a common metric. This metric also has the advantage of enabling direct assessment alongside other market, and non-market, costs and benefits, including avoided carbon emissions.

If such an approach were to be more widely applied to planning for windfarms, it could provide a framework for identifying, from a societal perspective, the cost:benefit ratio of each proposal. Such a ratio could then be the basis for approval, theoretically enabling the targets for renewable energy developments to be achieved in a cost-effective manner, i.e. at least social cost.

A number of research needs can be identified here, the first of which is the requirement for primary studies eliciting WTP values for residents in areas close to proposed windfarms, and for visitors to those areas. While the benefits transfer approach used in this study can be considered to have delivered a reasonable approximation for the purposes of this assessment, the technique, and the values derived, should be verified through the gathering of primary data.

Such research might usefully seek to value the marginal changes associated with factors such as increased turbine size/height, the addition or removal of turbines from proposed windfarms, and how values might vary across different landscape types.

A further need, and one that will become increasingly important over the next few years, is to understand, in quantitative terms, the issue of cumulative visual impact. Guidance from Scottish Natural Heritage (2005) gives an example of two windfarms either side of a valley, suggesting that taken together, the combined impact may be greater than the sum of the two individual impacts. While intuitively it could be argued that the two together have an increased impact, it could be expected that there might in fact be a 'diminishing marginal disutility' in terms of valuing the successive changes to the landscape. While it has in fact been observed from previous studies that people experience diminishing marginal effects of both gains and losses (Kahneman and Tversky, 1979; Knetsch, 2007), there is as yet no evidence either way specific to wind farm installations.

30.0 Conclusion

The analysis presented in this report demonstrates that under standard assumptions, with the windfarm displacing a gas-fired power station, and including a reasonable accounting for local disamenity impacts, the Clyde project delivers a net welfare gain of £1,445 million.

When the only available estimate for the non-use disamenity value for a large (160MW, 80 turbine) windfarm in Scotland (of £19.40 per household per annum for all 2.1 million Scottish households) is imputed, this reduces the welfare gain to £726 million. What this result means is that the Clyde project still delivers a net welfare gain to society.

That this non-use disamenity value can reasonably be applied to the Clyde wind farm in this way is far from certain. There are some very good reasons for doubting that this represents the true non-use value associated with this project.

A number of research questions follow from this analysis. One of these is the investigation of the non-use value cost category associate with wind farms. Specifically, further investigation is warranted to determine how this value varies across survey respondents when they are given further information on the location of wind farms. It would seem inappropriate to assume that this value is not invariant with location of both the windfarm and the respondent, the number of wind farms or through time. But there is currently no research that proves this.

However, of perhaps greater practical use would be primary studies establishing the changes in use value associated with the visual impact of developments. An improved understanding of such values could pave the way for a wider application of cost-benefit analysis in considering how to achieve targets for renewable energy deployment while incurring the lowest possible social cost.

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32.0 References

Alvarez-Farizo, B. & N. Hanley, 2002.: Using conjoint analysis to quantify public preferences over the environmental impacts of wind farms. An example from Spain, *Energy Policy*, vol. 30, no. 2, pp. 107-116.

Atkinson, G., Day, B. and Mourato, S., 2005. Underground, Overground? Measuring the Disamenity from Electricity Transmission Lines. In: D.W. Pearce (ed.) Valuing the Environment in Developed Countries: Case Studies, Edward Elgar, Cheltenham.

Awerbuch, S., 2003a. The True Cost of Fossil-Fired Electricity in the EU: A CAPM-based Approach, Power Economics, May 2003.

Awerbuch, S., 2003b. Determining the real cost: Why renewable power is more cost-competitive than previously believed. Renewable Energy World, James & James, (March-April)

Awerbuch, S. & Sauter, R., 2005a. Exploiting the oil-GDP effect to support renewables deployment. Energy Policy, Article in Press, Corrected Proof, available online 21 June 2005.

Awerbuch, S., 2005b. The Role of Wind Generation in Enhancing Scotland's Energy Diversity and Security: A Mean-Variance Portfolio Optimization of Scotland's Generating Mix. Report prepared for Airtricity, Greenock, Scotland.

Awerbuch, S., 2006. Personal communication – Current societal discount rate estimate for avoided coal and gas streams.

Bateman, I.J. & Langford, I.H., 1997. Non users' willingness to pay for a national park: an application of the contingent valuation method. Regional Studies 31, 571 – 582.

Bergmann, A., Hanley, N. & Wright, R., 2004. Valuing the attributes of renewable energy investments in Scotland. Paper available on Scottish Economic Policy Network website.

http://www.scotecon.net/publications/Hanley%20Full%20Report%20with%20appendices.pdf

Bergmann, A., Hanley, N. and Wright, R., 2006. Valuing the attributes of renewable energy investments. Energy Policy 34 (2006) 1004 – 1014.

Burall, P., 2004. Putting wind turbines in their place, Town and Country Planning, 73(2), pp. 60-63.

BWEA, 2005. Wind and the UK's 10% Target. Briefing Sheet, British Wind Energy Association, available on the BWEA website (accessed January 2006). http://www.bwea.com/pdf/briefings/target-2005-small.pdf

British Wind Energy Association: Calculations for Wind Energy Statistics (accessed February 2006)

http://www.britishwindenergy.co.uk/edu/calcs.html

Bullock, C. and J. Kay , 1997. Preservation and change in the upland landscape : the public benefits of grazing management, Journal of Environmental Planning and Management, 40, pp. 315-334.

Carbon Trust,2006. 'Expert Info – Conversion Factors' page on the Carbon Trust website (accessed Jan 2006) http://www.thecarbontrust.co.uk/energyCMS/CarbonTrust/pages_preview/page_64.asp

Dale, L., Milborrow, D., Slark, R., and Strbac, G., 2004. Total cost estimates for large-scale wind scenarios in UK. Energy Policy 32, 1949-1956.

DECC, 2009. Carbon Valuation in UK Policy Appraisal: A Revised Approach. Climate Change Economics, Department of Energy and Climate Change, July 2009.

Defra, 2006. Guidelines for Company Reporting on Greenhouse Gas Emissions, available on the Defra website (accessed January 2006) http://www.defra.gov.uk/environment/business/envrp/gas/index.htm

DTI, 1999. New and Renewable Energy: Prospects for the 21st Century: Supporting Analysis, ETSU, March 1999.

http://www.dti.gov.uk/renewables/publications/pdfs/support.pdf

DTI, 2002. The Renewables Obligation Order 2002: Regulatory Impact Assessment Department for Trade and Industry

http://www.dti.gov.uk/access/ria/renewables.htm

DTI, 2003. Energy White Paper "Our energy future – creating a low carbon economy", HMSO, London.

DTI, 2005. Digest of UK Energy Statistics 2005, Table 5.10, 'Plant loads, demand and efficiency'.

http://www.dti.gov.uk/energy/inform/energy_stats/electricity/dukes05_5_10.xls

DTI, 2006. The Energy Challenge: Energy Review, July 2006. HMSO, London

ECI, 2005. Wind power and the UK wind resource. A report for the Department for Trade and Industry, Environmental Change Institute, Oxford. http://www.eci.ox.ac.uk/renewables/UKWind-Report.pdf

Ek, K., 2002. Valuing the Environmental Impacts of Wind Power, a Choice Experiments Approach. Cited in Ladenburg, J. A. Dubgaard and Jesper Tranberg, 2006.

European Commission, 1999. ExternE: Externalities of Energy. National Implementation. Brussels

Garrod, G. D., Willis, K. G. and Saunders, C. M., 1993. 'Valuation of the South Downs and Somerset Levels & Moors Environmentally Sensitive Area Landscapes by the General Public', report to MAFF.

Garrod, G. D. and Willis, K. G., 1995. 'Valuing the Benefits of the South Downs Environmentally Sensitive Area', Journal of Agricultural Economics 46 (2), pp160-173

Garrod, G. & Willis, K., 1997. 'The non-use benefits of enhancing forest biodiversity: A contingent ranking study', Ecological Economics, 21, pp45-61.

Hamilton, S. and Schwann, G., 1995. Do High Voltage Electric Transmission Lines Affect Property Values? Land Economics, 71(4): 436-444.

Hanley, N., Bergmann, A. & Kim, Y., 2005. The Environmental Impacts of Renewable Energy: An Investigation of Public Preferences. Working Paper, University of Stirling

http://www.economics.stir.ac.uk/staff/hanley/EnergyEconomicsPaper.pdf

HMSO, 1989. Electricity Act 1989, London. Available at

http://www.opsi.gov.uk/acts/acts1989/Ukpga_19890029_en_2.htm

HMSO, 1997. Town and Country Planning (Scotland) Act 1997, London. Available at

http://www.opsi.gov.uk/acts/acts1997/1997008.htm

HM Treasury, 2002. Estimating the Social Cost of Carbon Emissions. Government Economic Service Working Paper 140, HM Treasury, London.

HM Treasury, 2006. GDP Deflators Index page on Treasury website. Accessed February 2006

http://www.hm-treasury.gov.uk/economic_data_and_tools/gdp_deflators/data_gdp_index.cfm

Ilex Energy Consulting and Strbac, G., 2002. Quantifying the system costs of additional renewables in 2020. DTI

http://www.dti.gov.uk/energy/developep/080scar_report_v2_0.pdf

Ilex Energy Consulting, 2005. Storage, Gas Prices and Security of Supply

Ilex Energy Consulting, 2006. Projections of the price for wholesale electricity in Great Britain

Kahnemanm, D., and Tversky, A., 1979. Prospect theory: an analysis of decisions under risk. Econometrica 47, 263-291.

Kennedy, S., 2005. Wind power planning: assessing long-term costs and benefits. Energy Policy, Vol 33, Issue 13, pp 1661-1675.

Knetsch, J.L., 2007. Biased valuations, damage assessments, and policy choices: The choice of measure matters. Ecological Economics, 63 (4), 684 - 689

Ladenburg, J. A. Dubgaard and Jesper Tranberg, 2006. Visual Disamenities from Off-Shore Wind Farms in Denmark – paper presented at the annual envecon conference, London, http://www.eftec.co.uk/img_upload/Ladenburg%20et%20al.pdf

MacLeod, M., Moran D., and Spencer, I., 2006. Counting the Cost of Water Use in Hydroelectric Generation in Scotland, Energy Policy Vol 34/15 pp 2048-2059

Milborrow, D. , 2005. Submission to Environmental Audit Select Committee, 'Keeping the lights on: Nuclear, Renewables and Climate Change'.

http://www.hm-treasury.gov.uk/media/E7C/A6/climatechange_BWEA_2.pdf

Mott MacDonald, 2003. The Carbon Trust & DTI: Renewables Network Impact Study, Annex 4: Intermittency Literature Survey and Roadmap.

http://www.thecarbontrust.co.uk/carbontrust/about/publications/Annex4.pdf

National Grid Transco, 2004. Seven Year Statement

Navrud, S., 2004. *MILJØKOSTNADER AV VINDKRAFT I NORGE* Sammendragsrapport til SAMRAM-programmet.Norges Forskningsråd.Notat .Institutt for Økonomi og Ressursforvaltning.Universitetet for Miljø- og Biovitenskap (UMB).

Ofgem, 2004. The Scottish Parliament Enterprise & Culture Committee: Renewable Energy in Scotland Enquiry, Submission from Ofgem, 10th February 2004

http://www.scottish.parliament.uk/business/committees/enterprise/inquiries/rei/ec04-reis-ofgemfollowup.htm

Oxera, 2004. Results of Renewables Market Modelling, report for the DTI, February 2004

http://www.dti.gov.uk/renewables/policy/oxeraresults.pdf

Pasqualetti, M. J., Gipe, P. & Righter, R. W. (Eds.), 2002. Wind Power in View: Energy Landscapes in a Crowded World, Academic Press, San Diego.

Pate, J. & Loomis, J.,1997. The effect of distance on willingness to pay values: a case study of wetlands and salmon in California. Ecological Economics 20, 199-207.

Price, C., 1993. Applied Landscape Economics: a Personal Journey of Discovery, Journal of Environmental Planning and Management vol. 36, 1 pp 51-63

Price, C. 2000. Valuation of unpriced products: contingent valuation, cost-benefit analysis and participatory democracy. Land Use Policy 17, 187 – 196.

Royal Academy of Engineering, 2004. The Cost of Generating Electricity. A Study carried out by PB Power for The Royal Academy of Engineering, March 2004

http://www.raeng.org.uk/news/publications/list/reports/Cost_of_Generating_Electricity.pdf

Scottish Executive, 2003. Securing a Renewable Future: Scotland's Renewable Energy http://www.scotland.gov.uk/Resource/Doc/47034/0014765.pdf

Scottish Executive, 2005. Scotland's Renewable Energy Potential, Future Generation Group Report

http://www.scotland.gov.uk/Resource/Doc/69582/0017404.pdf

Scottish Executive, 2006a. Scottish Executive response to UK Energy Review, June 2006

http://www.scotland.gov.uk/Resource/Doc/129622/0030898.pdf

Scottish Executive, 2006b. Matching Renewable Electricity Generation with Demand

http://www.scotland.gov.uk/Publications/2006/04/24110728/0

Scottish Renewables, 2006. Delivering the new generation of energy: Route map to Scotland's renewable future

http://www.scottishrenewables.com/data/reports/SRF%20Route%20Map.pdf

Schleisner, L., 1999. Life cycle assessment of a wind farm and related externalities. Renewable Energy 20, pp 279-288.

Simpson, D., 2004. Tilting at Windmills: The Economics of Wind Power, David Hulme Institute, Edinburgh, Occasional paper Number 65
http://www.davidhumeinstitute.com/DHI%20Website/publications/hop/Wind%20Power%20paper.pdf

SNH, 2005. Guidance: Cumulative effect of windfarms, Scottish Natural Heritage, Version 2, 13.04.05 available at
http://www.snh.org.uk/pdfs/strategy/Cumulativeeffectsonwindfarms.pdf

Sutherland, R.J. & Walsh R., 1985. Effect of distance on the preservation value of water quality. Land Economics 61, 281-291.

Toke, D., 2005. Explaining wind power planning outcomes: Some findings from a study in England and Wales. Energy Policy 33, 1527 – 1539.

UKERC, 2006. The Costs and Impacts of Intermittency: An assessment of the evidence on the costs and impacts of intermittent generation on the British electricity network, UK Energy Research Centre, March 2006.

Van der Horst, D., 2007. NIMBY or not? Exploring the relevance of location and the politics of voiced opinions in renewable energy siting controversies, Energy policy 35, 2705 – 2714.

Warren, C., Lumsden, S., O'Dowd, S. & Birnie, R., 2005. 'Green On Green': Public Perceptions of Wind Power in Scotland and Ireland. Journal of Environmental Planning and Management, Vol 48, Issue 6, pp 853-875.

Willis, K.. and Garrod, G., 1993. Valuing Landscape: a Contingent Valuation Approach, Journal of Environmental Management, 37, 1-22.

Toke, D., 2005, Explaining wind power planning outcomes: Some findings from a study in England and Wales. Energy Policy 33, 1527– 1539.

UKERC, 2006, The Costs and Impacts of Intermittency: An assessment of the evidence on the costs and impacts of intermittent generation on the British electricity network, UK Energy Research Centre, March 2006.

Van der Horst D., 2007, NIMBY or not? Exploring the relevance of location and the politics of voiced opinions in renewable energy siting controversies. Energy policy 35, 2705–2714.

Warren C., Lumsden, S., O'Dowd, S. & Birnie, R., 2005, 'Green On Green': Public Perceptions of Wind Power in Scotland and Ireland, Journal of Environmental Planning and Management, Vol. 48, Issue 6, pp 853–875.

Willis, K. and Garrod, G., 1993, Valuing Landscape: a Contingent Valuation Approach, Journal of Environmental Management, 37, 1-22.

Chapter 6: Discussion

The central contention of this thesis is that a clear understanding of the nature of barriers to the development of renewable energy in the UK is necessary not only to enable Government targets to be achieved, but to ensure that they can be achieved in an efficient manner. The research reported in the four main chapters highlights a number of important issues in respect of these barriers, and aids understanding of the nature of constraints on the development of two areas of renewable energy with significant potential in the UK. Such understanding, if translated into effective policy responses, should allow for a more cost-effective approach to increasing the supply of perennial energy crops, and rolling out the development of onshore wind farms.

Key messages in respect of perennial energy crops include:

- UK farmer adoption of perennial energy crops is likely to be significantly below Government expectations unless a number of issues are tackled. Specifically, concern about the security and stability of income from contracts is preventing uptake at gross margins that should be attractive to farmers.

- Simply increasing the returns available by increasing the support for combustion of perennial energy crops via the Renewables Obligation is an unnecessarily expensive way of increasing levels of supply. Tackling concerns over security and stability of income from contracts, such as through a form of insurance, would create the pre-conditions for farmers to consider adoption at lower gross margins.

- Cashflow is also a concern, specifically for SRC willow where there is a significant delay between planting and harvesting. This is something that has started to be addressed through some of the more innovative contractual arrangements, such as via Bical for supply to Drax, but such approaches should become more widespread.

Key messages in respect of onshore windfarms include:

- The current approach to planning for onshore wind has no mechanism to ascertain the welfare impacts of specific proposals in a manner that is consistent with standard UK Government project appraisal techniques, which use CBA to incorporate market and non-market costs and benefits.
- Such an approach, using cost-benefit analysis, is demonstrated to have the potential to place a monetary value on the apparently intangible issue of visual impact, which is one of the most contentious aspects of onshore windfarms.
- Furthermore, applying this framework to wider consideration of the relative merits of competing schemes should enable Government targets to be met at the lowest possible social cost.

The messages presented above are unavoidably linked to the analytical framework adopted for this study. In approaching the research for this thesis, a number of decisions have been made as to the techniques to apply, in areas where there are other ways of framing the analysis. Moreover, there are a number of possible criticisms of the approaches that have been taken. The following sections will explain the rationale for the way in which the research has proceeded, examine alternatives, and justify the chosen methods.

33.0 Approach to modeling farmer uptake of perennial energy crops

The initial approach was intended to focus simply on the development of a mathematical model, illustrating uptake of perennial energy crops at different gross margins. The intention was to attempt to incorporate variables such as risk aversion, through the use of weighted goal programming. This was largely driven by the stated requirements of the NERC funded research grant, as part of the TSEC-Biosys programme. However, it soon became clear that perennial energy crops had a number of attributes that precluded a conventional analysis of uptake based on incremental increases in return and weighted farmer preferences.

Reviewing the available literature, it was evident that perennial energy crops are still seen as a particularly novel enterprise, and that almost a decade after the collapse of the ARBRE scheme, the impact of this event continues to taint farmers' views of these crops. It was therefore deemed necessary to gain a more detailed understanding of farmers' specific attitudes and behavioural intentions in respect of perennial energy crops. Such an approach is consistent with the trend, over the last two decades, in agricultural economics, away from simply considering farmers as rational market participants, to attempting to delve deeper into understanding individual motivations.

This approach was also considered particularly appropriate due to the stage of development of the perennial energy crop market in the UK. With low levels of uptake, confidently identifying an observed supply curve against which to calibrate a modelled supply curve would have been a very difficult undertaking. In addition, the influences on such crops from both agricultural and energy policies, both of which have been in a relative state of flux over the period of this research, suggested strongly that understanding attitudes, influences and behavioural intentions would yield the most useful insights.

33.1 Investigating farmer behaviour

Mainstream economics teaches that individuals make decisions based on the expected resulting change in their level of well-being (or utility). An increase in an individual's utility may arise from a number of events, such as the purchase of a new car, a pay rise, or an improvement in health or the local environment (Edwards-Jones, 2006). However, utility is difficult to measure. For others subject to the same event, the increase in utility may be larger or smaller. Moreover, for the same person, the effect of an identical event at different points during their lifetime may not always deliver the same increase in utility (Edwards-Jones, 2006).

For economists, the concept of utility is very useful, with the assumption that humans seek to maximize their levels of utility forming the basis of traditional economic modeling. However, in practice, as measurement of utility is problematic, economists make the assumption that money can act as a reasonable proxy for the extent to which an individual's utility is changed by a particular event (Edwards-Jones, 2006). Thus agricultural economic modeling, used to predict likely levels of uptake of particular activities, given the relative financial attractiveness of competing activities, has for many years assumed the existence of the rational profit maximizing farmer (Wallace and Moss, 2002; Revell and Oglethorpe, 2003). This approach was used by University of Cambridge (2005) to estimate the likely uptake of perennial energy crops by UK farmers.

While in many cases decisions may well be dominated by financial concerns, a range of other, non-financial factors are understood to influence the adoption of new products, policies and technologies (Jones, 1963; Rogers, 2003). The need to understand these factors has become increasingly important in recent years with the growing policy focus on encouraging the supply of environmental goods by farmers. In attempting to anticipate likely farmer response to opportunities presented by novel activities such as perennial energy crops (Sherrington et al., 2008) or voluntary schemes promoting biodiversity enhancement and water management, mainstream agricultural economics has increasingly drawn on insights from disciplines such as sociology and psychology (Edwards-Jones, 2006).

Research into adoption decisions of farmers has identified five key sets of non-financial variables that can play an influential role. These are: farmer characteristics, household characteristics, farm structure, the wider social setting and the characteristics of the innovation to be adopted (Edwards-Jones, 2006).

Age, gender, attitude to risk, education and personality are all farmer characteristics known to be important in adoption decisions, while farm household characteristics known to be important include work patterns of the spouse, level of pluriactivity, and stage in the family cycle (Jones, 1963; Bowler, 1979; Brotherton, 1989, 1991; Nkonya et al., 1997; Willock et al., 1999b; Vanslembrouck et al., 2002; Sheikh et al, 2003). The structure of the farm business, such as farm type and size, and levels of indebtedness are also understood to influence decision making (Jones, 1963; Potter and Gasson, 1988). Sherrington et al., (2008) found that adoption decisions in relation to perennial energy crops may be based on a broad range of criteria including the greater perceived risks involved in such activities, reduction of farm business flexibility, and life stage of the farmer.

Factors relating to the social setting such as attitudes of trusted friends, local culture, levels of extension, information flows, the policy environment and institutional structures have more recently been identified as important influences on decision making (Guerin and Guerin, 1994; Neupane et al., 2002; Mathijs, 2003; Solano et al., 2003), and are now key considerations in models used to understand and anticipate behavioural intentions (Beedell and Rehman, 2000; Mattison and Norris, 2007). Such considerations are clearly evident in the case of perennial energy crops. Farmers perceive a lack of trustworthy information in relation to perennial energy crops, with many taking a wait-and-see attitude, through observation of the crops of neighbouring ‘early adopters’ (Sherrington et al., 2008). There are also concerns about institutional risk in terms of the security of income from available contracts, and the policy risk of novel activities that are at the interface of energy and agricultural policies (Sherrington et al., 2008).

The fifth set of variables identified relates to the characteristics of the product or policy to be adopted. Much research in this area focuses on agri-environment schemes, where factors relating to participation include the voluntary nature of the scheme, scheme duration, payments, flexibility of the scheme and its impact on farm management (Guerin and Guerin, 1994; Morris and Potter, 1995; Wilson, 1997). Another important factor is the level of paperwork involved, with requirements for lengthy form filling having been shown to cause stress among farmers and lead to lower levels of scheme adoption (AgraCeas, 2003; McGregor et al., 1995; Boulanger et al., 1999). Farmer concern over paperwork is also evident in the context of the various support schemes for perennial energy crops (Sherrington et al., 2008).

In addition to the above factors, and financial concerns, aspects of a farmer's psychological make-up, such as attitudes, also influence an adoption decision (Austin et al., 2001; Willock et al., 1999a and b). Attitudes have been defined as 'a positive or negative response towards an attitude object (where an attitude object may be a person, idea, concept or physical object' (Willock et al., 1999b), and as 'a psychological tendency that is expressed by evaluating a particular entity with some degree of favour or disfavour' (Eagly and Chaiken, 1993).

Considerable attention has been given to the study of farmer attitudes in recent years, because of the realization amongst agricultural scientists that attitudes have an important influence on farmer behaviour, and that relationships may exist between attitudes and other characteristics such as education (Edwards-Jones, 2006). Such relationships have long been understood in the field of social psychology, with attitudes acknowledged to interact with other personal aspects to influence behaviour (Ajzen and Fishbein, 1980; Ajzen, 1991). Models developed for social psychology research are increasingly being used in many areas, and using such an approach to underpin the work for this thesis relating to farmer adoption of perennial energy crops has yielded considerable insights of significant use to policy makers.

Three social psychology approaches predominate in considering uptake of new techniques and technologies in the agricultural context - the Theory of Reasoned Action (TORA) (Ajzen & Fishbein, 1980), its extension the Theory of Planned

Behaviour (TPB) (Ajzen, 1991), and Diffusion Theory, which has been successfully applied in rural situations since the 1940s (Fliegel, 1993).

Diffusion is defined by Rogers (1995) as "the process by which an innovation is communicated through certain channels over time among members of a social system", and the theory has been widely used to consider the uptake of agricultural innovations such as herbicides, hybrid seed and fertilizers. Seminal research by Ryan and Gross (1943) on the diffusion of sowing hybrid corn by Iowa farmers in the USA provided the fundamental characteristics of the theory: the classic "diffusion of innovations" paradigm. The study promoted the significance of communication as a construct in the diffusion model and provided the generic bell-shaped and sigmoid curves of uptake on which much rural sociology research has been based (Jackson et al., 2006).

Communication was one of the recurring themes in Rogers' (1995) description of each category of adopter, termed 'Innovators', 'Early Adopters', 'Early Majority', 'Late Majority' and 'Laggards', with the geographical extent of their communication reflecting their position on the curves. For the networks of Innovators, Rogers (1995) used the term 'cosmopolite' to reflect the great distances over which they communicated, whereas laggards were the most fervent 'localites', viewed as 'near isolates in the social network', (Rogers, 1995).

The adoption of an innovation is seen as a process and follows five main phases in which different information sources are important (Rogers 1995, 2003; Tutkun et al., 2006).

1) Knowledge of the innovation – in this phase, mass media plays an important role as a source of information
2) Persuasion and evaluation of the attributes of an innovation, i.e. formation of attitudes as to its advantages and disadvantages – friends and neighbours are the most important sources of information at this stage
3) Decision whether or not to adopt the innovation. Through actively seeking and processing information the aim is to reduce uncertainty about the

advantages and disadvantages – again friends and neighbours are important information sources

4) Implementation of the innovation – sometimes an adaptation of the innovation to the farm environment may be needed and personal experience is very important at this stage
5) Confirmation – i.e. the individual seeks reinforcement for the innovation decision already made.

However, as Fisher et al. (2000) note, diffusion differs from adoption in that it is the process by which new technologies are spread among users, whereas adoption is an individual, internal decision. While an awareness of the process by which such diffusion in respect of perennial energy crops might take place is useful for this research, understanding likely individual farmer *behaviour* in respect of adoption is the focus. Therefore, the decision was taken to use the Theory of Planned Behaviour.

The Theory of Planned Behaviour, and it's predecessor, the Theory of Reasoned Action have substantial empirical support, and have successfully been used to predict behavior in a variety of practical contexts including smoking (e.g. Morrison et al., 1996; Norman et al., 1999), adherence to a medical regime (Conner et al., 1998), choosing a career (Vincent et al., 1998), composting (Kaiser et al., 1999), as well as for farmer decision making (Lynne et al. 1995; Beedell and Rehman 1999, 2000; Trumbo and O'Keefe 2001, Defra 2006; Mattison & Norris, 2007).

The foundation of the TPB is the subjective expected utility theory (SEU) and it is therefore assumed that individuals behave in a rational way, in accordance with their subjective expected or perceived utility (Fishbein & Ajzen, 1975). This aspect has been criticized on the basis that the TPB presents a picture of decision-making processes that is too rational and calculated, without taking into account that people often act based on habit and automatic or unconscious processes (Bagozzi 1992; Bagozzi and Kimmel 1995). This implies that despite its predictive successes, the TPB may not accurately reflect the actual psychological processes involved in decisions to perform a particular behavior.

However, this criticism is common to all attitude theories which use an expectancy-value format when attempting to explain behavior, including utility theory in economics: the role of habit is not well represented. Moreover, in the case of adoption of perennial energy crops, a novel activity, the use of habits would not necessarily be a useful indicator of adoption intentions

One common method for addressing the lack of emphasis on automatic and unconscious processes in the TPB is simply to propose a different model. However, none of the competing models (e.g., Bagozzi 1992) have generated enough research or gathered enough empirical evidence to show that they achieve generally better prediction or understanding of the factors influencing decision making (Hoffman et al., 2004).

Proponents of expectancy-value models in general, and of the TPB and TRA in particular, typically point out that the TPB does predict behavior fairly well and thus has at least predictive validity, one of the requirements of external validity. Sutton's (1998) meta-analysis of research using the TPB indicated that, on average, the TPB explains 40% to 50% of the variance in intentions to perform a behavior, and 19% to 38% of the variance in actual behavior. Compared to many effects in psychology, even the smaller proportion of behavior variance explained is notable (Hoffman et al., 2004).

A second criticism of the Theory of Planned Behavior relates to confusion over the meaning of the constructs. The primary example given for this is the construct of perceived behavioral control. Ajzen (1985) has stated that this concept is similar to the concept of self efficacy proposed by Bandura (1977a, 1977b). Self-efficacy refers to a person's beliefs about whether s/he can be instrumental in a given situation. However, some empirical research indicates that self-efficacy and perceived behavioral control are different constructs (e.g., Manstead and van Eekelen 1998).

According to this research, self-efficacy represents a concept consistent with the way it has been classically defined: whether one perceives oneself as possessing the skills and abilities necessary to control the situation. Perceived behavioral control seems to capture whether one believes it is possible to control the situation. A recent metaanalysis has indicated, however, that there is only weak evidence for distinguishing between perceived behavioral control and self-efficacy (Armitage and Connor 2001).

A number of empirical and review articles suggest that understanding of behavior may be improved by adding variables to the basic TPB model to address criticisms relating to the influence of unconscious processes such as habit, and the confusion between perceived behavioral control and self-efficacy (Aarts et al. 1998; Connor and Armitage 1998; Manstead and van Eekelen 1998; Richard et al. 1998; van der Pligt and de Vries 1998).

One of the most commonly recommended additional variables is past behavior (Connor and Armitage 1998). Empirical research indicates that past behavior is able to account for variance in behavior above that attributable to the TPB components (Aarts et al. 1998; Connor and Armitage 1998). However, as noted above, in the case of adoption of perennial energy crops, a novel activity, the use of past behaviour may not necessarily be a useful indicator of adoption intentions.

Of the TPB studies applied to farmers' decision making, most of have focused on conservation behaviors. For example, Lynne et al. (1995) examined the adoption of water conservation technology by Florida strawberry farmers. Their research supported Ajzen's decision to add perceived behavioral control to the Theory of Reasoned Action in his proposal of the TPB because both perceived and actual control explained a significant proportion of the variance in water conservation technology adoption by these farmers.

In other studies of farmers' conservation behavior, Beedell and Rehman (1999, 2000) found that, consistent with the TPB, farmers' pre-existing attitudes and social pressures determined why and in what manner they chose to manage the hedges on their land. "Conservation-minded" farmers were more likely to consider the conservation benefits of hedge management in their decisions. These farmers also felt under greater social pressure to manage their hedges, as they tended to belong to one or more conservation groups. This application of the TPB suggests that it can offer useful insight into farmers' decision-making processes and their behavior.

A further criticism is that behavioural decision-making models such as the TPB and TORA rely on self-reports, despite evidence suggesting the vulnerability of such data to self-presentational biases (e.g. Gaes et al., 1978). Hessing et al. (1988) examined the TORA in relation to tax evasion, and contrasted self reports with official documentation. Findings indicated that attitudes and subjective norms correlated with self-reported behaviour, but did not correlate with documentary evidence, in spite of considerable effort to maintain the anonymity of respondents. However, in the context of adoption of perennial energy crops, there is no *a priori* reason to expect that farmers would deliberately choose to misreport their intentions.

While there will always be a number of potential shortcomings to any research approach, evidence from narrative and meta-analytic reviews suggest that the TPB is indeed a useful and appropriate model for predicting a wide range of behaviours and behavioural intentions (Armitage and Conner, 2001).

33.2 Criticisms of the chosen approach

From the point of view of the research council, it could be argued that the study has failed to deliver an accurate answer to the level of adoption that might be expected given a certain level of return. However, the response to this is that it is too early to state with any confidence the level of uptake that might be achieved, and moreover, uncovering the key issues identified in both the focus groups and the postal survey, has delivered valuable insights of direct policy relevance. A greater focus on developing models that covered a number of scenarios, and incorporated goal seeking approaches might well have produced a range of possible levels of uptake, but would have been to the detriment of greater understanding of the actual barriers to adoption as considered at the farm-level.

It would also be possible to criticise the focus group approach in that such groups can always be considered self-selecting, to a certain degree, are not representative, and are potentially dominated by the views of a few. However, the very nature of the extent of energy crop adoption meant that few people had experience of the crops, and thus their views were useful as the first step in the wider Theory of Planned Behaviour based research. It has never been suggested that the focus groups were representative of the wider farming community, with the second stage of the research, the postal survey being relied upon as the way to establish a statistically significant response to key issues.

Again, with the postal survey, only specific areas of the country were targeted, leading to potential claims that the views presented were not representative of the UK farming community as a whole. However, the difficulty here, reflecting once more the immaturity of the energy crop market, is that in many areas there simply are no perennial energy crops, and no significant sources of demand. It was considered more useful to focus on areas where farmers knew that others had already adopted and that sources of demand existed within a reasonable distance.

One of the early hopes for the Theory of Planned Behaviour research was that findings could, at a later date, be incorporated into a model using Positivistic Mathematical Programming. Research undertaken for Defra by a team of agricultural economists at Reading University (Defra, 2006) was intending to achieve such a process of integration. Unfortunately, their efforts were unsuccessful, and it was decided not to attempt to integrate the findings from the postal survey research into mathematical modelling. Notwithstanding, this setback, as a stand-alone piece of research, the output from the postal survey using the Theory of Planned Behaviour has delivered a number of useful findings.

The mathematical model is therefore applied in the full knowledge that at the farm level, there are a number of significant barriers to adoption. Having gained this understanding, the decision was taken to abstract from these known barriers in the modelling, and model uptake in the conventional manner, treating the decision to adopt as one simply based on financial considerations, i.e. the return available from these activities. This achieved two key objectives.

Firstly, in updating the research undertaken by University of Cambridge (2005), the intuitive effect of increased prices for conventional crops became evident in that higher returns for energy crops were required to stimulate a certain level of uptake.

Secondly, the gap between modelled and actual uptake at current prices highlights the existence and importance of the identified barriers to adoption, along with supporting the contention that directly tackling the known barriers should bring about adoption at a lower cost than through increasing support levels via the Renewables Obligation.

Thus while the modelling does not provide 'an answer', it does usefully illustrate the juxtaposition of conventional economic understanding of adoption with the more detailed behavioural studies that preceded the model's application. In tackling the research in this order, the all important context within which the model's results should be interpreted has been fully developed. In so doing, the Theory of Planned Behaviour research, and the mathematical modelling studies serve to complement each other in bringing about a fuller understanding of the key issues.

34.0 Planning for onshore windfarms

The research that led to the publication of the paper addressing the economics of onshore wind generation, including externalities, was commissioned by Airtricity Ltd., a Dublin based developer of on and offshore windfarms. Airtricity sought an impartial assessment of one of their proposed schemes, using techniques and values in line with UK Treasury project appraisal guidance, in order to establish the overall costs and benefits of the proposal.

From reviewing the literature it soon became clear that no such study had ever been undertaken for an onshore windfarm, which was quite remarkable considering that the development of onshore wind in the UK engenders such strong opposition, typically related to the perceived negative visual impact. That no attempts had been made to understand this opposition using an approach such as a contingent valuation study that could be applied within the framework of CBA was surprising.

A reason for this might be that the predominant framework for assessing the merits of proposed windfarms is that applied through the planning process, where impacts are assessed using an ordinal scale. Monetised impacts, both costs and benefits, as established for appraisals of projects such as road schemes, do not feature. This is arguably a significant weakness of the planning system, especially if trying to establish a consistent approach across the country. While it is difficult enough to assess whether an individual windfarm project should go ahead, to explain why one has been refused and another allowed is more difficult, and will become increasingly so with the large number of pending planning applications.

There is, furthermore, concern as to the weight currently given by planning authorities to the various positive and negative impacts that arise. Specifically, some landscape protection groups feel that carbon dioxide reductions, which can be measured in terms of their contribution to government targets, heavily outweigh other perhaps less tangible environmental and landscape considerations in planning judgements in the UK (Ramblers Association Scotland 2005, CPRE, 2005). While some may consider 'aesthetic issues' as difficult to equate with the 'fundamental risks that continued fossil fuel use poses to natural systems and society' (WWF-UK, 2003), it is technically possible to quantify the welfare changes arising from both the visual impact and the avoided emissions associated with a windfarm. Thus potential trade-offs can be examined.

Using a cost-benefit style approach would appear to have a number of attractions, but would represent a significant change in emphasis from the current process of landscape evaluation that is undertaken as part of the planning process. It is therefore worth considering the theoretical roots of the two approaches in order to assess whether the argument that applying cost-benefit analysis could enable a more socially cost-effective deployment of onshore windpower, can be sustained

Some of the relevant issues have been touched upon to a certain extent in Chapter 5, and will be more fully discussed below.

Firstly, understanding of public perceptions of windfarms is reviewed. Then the current planning approach is investigated. Following this, consideration is given to the techniques, merits, difficulties and possible objections to capturing the visual disamenity associated with windfarms in monetary terms. Further research needs are then discussed.

34.1 Public perceptions of windfarms

Public opinion is generally positive towards wind power (Sustainable Development Commission, 2005; Devine-Wright, 2005; Krohn & Damborg, 1999). But when it comes to specific projects, local and organised opposition can be significant (Ellis et al., 2007; Haggett, 2004). Research confirms that the strongest impacts on attitudes to wind farm proposals arise from the projected aesthetic value of turbines and perceived impact on landscape (Pasqualetti et al., 2002 ; Burall, 2004, Wolsink,2007a).

Most attitudinal research in this field has focused on the contrast between opposition from local residents (many of whom support wind power in principle) and the high levels of support for wind among the public in general. Some have characterised this difference as one that can only be explained in terms of the 'deviant' behaviour on the part of the objectors who are then neatly labelled as NIMBYs (e.g Righter, 1996; Elliot, 1997, Kahn, 2000). Ellis et al. (2007) however, argue that such analysis has tended to project monolithic notions of objection that fail to grasp the intricacies of local disputes and tend to focus on objectors as the key obstacle to wind farms rather than encouraging an understanding of the complete dynamic of the dispute (Smith & Marquez, 2000).

Evidence of this is an assumption that is found in policy documents (e.g. RCEP, 2000; DTI, 2002) and some academic texts (e.g. Strachan et al., 2006) that 'awareness-raising' should be the main strategy for bringing objectors round. This view is supported by Short (2002) who considers that "opinion is formed not by experience, but rather by ignorance, misinformation, prejudice and fashion". In such a way the objections voiced by local residents are deemed by some groups (e.g WWF-UK, 2003) to be less valid than the national and global concerns that are being tackled, in part, by the promotion of renewable energy.

Arguably such a view of 'opposition through ignorance' fuels the fears of recreation and landscape protection groups that visual impact is not given due importance in planning judgements in the UK (Ramblers Association Scotland 2005, CPRE, 2005). However, as Ellis et al. (2007) point out, far from being ignorant, many objectors appear extremely well informed about the subject (e.g. Etherington, 2006), and their views result from deeply held values, consistent with their opposition to individual schemes even when they may support wind power in principle. In fact it is recognised in the fields of social and environmental psychology that it is entirely consistent to both approve of windpower and object to a particular scheme, as 'windpower in general' and 'a specific windfarm proposal' are two entirely separate 'attitude objects'. As Wolsink (2007b) notes, attitudes to wind power are fundamentally different from attitudes towards wind farms.

Most research in this area has described and attempted to account for public reactions to wind energy development (Devine-Wright, 2005). While this has brought about a greater understanding of the nature of objections to windfarm proposals, little has been done to quantify such opposition in a way that can allow comparison with other positive and negative impacts.

34.2 The current approach to evaluation through planning

For larger wind power projects in the UK, (usually those over 5 MW), the developer is required to produce an independent Environmental Impact Assessment (EIA) to investigate specific concerns such as landscape, noise and wildlife effects (Sustainable Development Commission, 2005).

The results of the EIA are published in an Environmental Statement (ES), which is a publicly available document that will be used in the consents process. It must be accompanied by a non-technical summary, written in an accessible way and available free of charge, usually from the developer (Sustainable Development Commission, 2005).

EIA regulations (HMSO, 2000) require that "the aspects of the environment likely to be significantly affected by the development" are included in the ES, but offer no specific guidelines on definitions of significant. While the prediction and then evaluation of significance is central to EIA, it is also fraught with methodological difficulty. University of Newcastle (2002) states that 'Ultimately, significant is what individuals, people, organisations, institutions, society and/or policy say is significant – it is a human evaluative and subjective judgement on which there may or may not be consensus'.

For landscape and visual effects, the LI-IEA guidelines (LI-IEA, 1995) are widely referred to in EIA, and appear to have become the *de facto* national standard (University of Newcastle, 2002). However, a subsequent advice note (Landscape Institute, 1999) emphasises that the guidelines are general, non-prescriptive, and not intended to offer a preferred methodology. In the second edition of the guidance (LI-

IEMA, 2002), stress is laid on “informed and well reasoned judgement supported by thorough justification”, as well as the need to consider issues, including significance on a case-by-case basis (Box 7.3, IEMA, 2002).

While broad professional landscape consensus does exist, as the similarities in the examples given in Appendix 6 of LI-IEMA (2002) show, detailed differences of interpretation are inevitable (University of Newcastle, 2002). Moreover, University of Newcastle (2002) argues that “the definitions and judgements of significance contained within an ES are ultimately those of the developer and/or consultant, even allowing for the existence of a degree of consensus among landscape professionals who would be expected to share some common standards and norms”. While University of Newcastle (2002) intends no criticism of the honesty or professional integrity of the parties in their case studies, they feel “it is a truism that a developer must want to minimise the number of significant impacts identified, and that a professional is torn between their role as an expert and their role as an advocate”.

While some ESs may be little more than promotional material for developers, University of Newcastle (2002) argues that “even in ostensibly fair, balanced and unbiased statements there can exist more subtle and entirely understandable nuances and judgements that can be challenged”. As a result of this, decision makers, from development control through to a public enquiry, may feel free to accept or reject many definitions and judgements unless consensus exists (University of Newcastle, 2002).

This illustrates and supports the contention of Appleton (1975) that the lack of an “aesthetic theory” handicaps objective professional evaluation of landscape and landscape change.

To take the example of Scotland, where much of the UK’s onshore wind capacity is due to be located, guidance from the Scottish Executive states that:

“Consideration of the significance of any adverse impacts of a renewable generation proposal should have regard to the projected benefits of the proposal in terms of the scale of its contribution to addressing climate change through its contribution to the

Scottish Executive's targets for renewable energy. A relevant consideration should be whether such a scale of renewables contribution could be realised with fewer or lesser impacts in a different location or through several smaller projects" (Scottish Executive, 2007).

The Scottish Executive's guidance does not, however, outline how to achieve the appropriate balance. While the methodology for landscape and visual impact assessments is well developed (University of Newcastle, 2002; Landscape Institute & Institute for Environmental Management and Assessment, 2002), the question remains as to how tonnes of avoided carbon dioxide emissions should be compared against the results of a visual impact assessment that presents impact scores using an ordinal scale? In the absence of a common scaling denominator it is not possible to establish in a transparent and consistent manner whether a project's costs outweigh the benefits, or moreover, to compare competing projects and rank them.

The need to measure more fully the perceived visual and aesthetic impacts of wind farms is evident from a review of the academic literature (Khan, 2003; Strachan & Lal, 2004). However, while such impacts continue to be measured using ordinal scales based on expert-led evaluation, the problem of comparison with other impacts remains.

An alternative yet complementary approach, is valuation, where a monetary value is assigned to a landscape (or indeed any change in that landscape), enabling comparison with other monetised impacts on a like-for-like basis. Following this approach, it is possible, through cost-benefit analysis (CBA), to quantify the welfare impact, in monetary terms, of any individual windfarm proposal, to ascertain whether or not it delivers a net benefit to society. Competing projects can then be ranked by their benefit:cost ratio, or by the size of their net benefit to society. While such an approach could not replace all aspects of the evaluative process undertaken through the development of an Environmental Statement, a formal assessment of the welfare impacts of a proposal could provide a valuable addition to the 'toolkit' available to the planning authority.

While quantifying the welfare impact is attractive for the reasons outlined above, the use of CBA, especially to consider environmental and aesthetic issues does provoke controversy. One of the main areas where CBA is thought by some to be lacking is in the way it deals with issues of equity (e.g. Sagoff, 1988). In neo-classical welfare economics, economic value is determined by effective demand, i.e. by willingness to pay, backed up by an *ability* to pay. Thus if someone *would* pay to secure a certain benefit but was unable to afford anything, this would be treated as zero WTP. Effective demand as a measure of preferences has its attractions, but one weakness is the way in which the vote in the market place is unequal (Hanley & Spash, 2003). Accordingly, and reflecting wider societal inequalities, an equal opportunity to influence resource allocation could be argued to require an equitable income distribution. However, if the existing income distribution is tolerated by society, by implication, the outcome of a CBA, based on this distribution, may be treated as an acceptable basis for decision-making.

Similarly, the Kaldor-Hicks criterion, which states that a resource allocation is desirable if the gainers *could* compensate the losers and still be better off, is frequently criticised, on the basis that compensation is theoretical, i.e. it need not take place. Hence distributional impacts are not explicitly taken into account, but may be considered by the decision-maker outside of the CBA. An alternative, following Bergson (1938), is to define a social weighting within the CBA, perhaps to suggest that the poor should benefit to a greater extent than the rich. This would be consistent with the observation of the diminishing marginal utility of income, whereby an extra unit of income delivers less marginal utility to a rich person than to a poor person (Layard et al., 2008). While individual utility is difficult to measure, CBA sidesteps this issue by using money as a reasonable proxy for utility. This would indeed suggest there is a place for the inclusion of weighting. However, such weights would need to be set, an act which would itself have to be a matter of political judgement.

Over time it could be assumed that the government might use transfer payments to counter systematic redistributions following from implementation of the Kaldor-Hicks criterion, but if these redistributions do not take place, then the adherence to

CBA may well lead to adverse distributional consequences. However, the application of weights to CBA would itself lead to problems of inconsistencies in the evaluation of competing projects, and thus the focus of CBA remains on allocative efficiency, rather than distributional equity, with the latter being left to government to achieve through transfer payments.

For many people the attribution of a monetary value to landscapes, species or indeed built heritage is distasteful, and incommensurate with their own beliefs. Often a landscape may be described as 'priceless', and within a contingent valuation study an individual would refuse to state a WTP for a change to that landscape. Such a response would count as a zero bid. Such 'lexicographic preferences' violate the exchange value assumption in neo-classical economics , i.e. the individual cannot be compensated for the loss of a quantity of one good by increases in the quantity of one or more other goods, no matter how small the former or large the latter (Hanley & Spash, 2003).

This was famously highlighted by the Roskill Commission, which valued a Norman church at just £50,000 when seeking to establish through CBA the best location for a third London airport (Lichfield, 1971). The resulting controversy suggested that this was clearly an instance where lexicographic preferences were in evidence.

However, while such preferences may exist for iconic landscapes or locations, they will not be universally held. Moreover, for landscapes considered to be of 'lesser value', such preferences may be entirely absent. A number of techniques exist for dealing with these preferences within contingent valuation surveys, and if consistently applied enable reliable cross-comparison of values (Hanley & Spash, 2003).

While there may be a number of difficulties in applying economic valuations to landscape, they have a number of advantages compared with other techniques, as will be outlined below. Moreover, failing to incorporate these values within the widely applied framework of CBA may in fact risk landscape issues being left out of important decision-making processes (Swanwick et al., 2007).

34.3 Evaluation or valuation of impacts?

Evaluation of a landscape is the process of scoring or rating its quality, whereas valuation assigns an economic (monetary) value to the landscape or its attributes.

While evaluation is the more widely practised of the two techniques, the absence of a common scaling denominator effectively precludes analysis of many of the types of trade-offs that are of high policy relevance. For example, one cannot determine whether to save a superbly rated landscape (rating 23), which is remote with 500 annual visitors, or an ordinary rated landscape (rating 10) that is visited by 100,000 (Price, 1993). Likewise we cannot compare different degrees of impact on different landscapes or aggregate landscape impacts for alternative project designs (Santos, 1998).

Instead of resolving this shortcoming, landscape research has moved onto a formal process of Landscape Character Assessment (LCA), which guides current landscape planning. LCA is unambiguously subjective but within a process that claims to reconcile a range of concepts and elements that are deemed relevant in most cases of characterisation (see Swanwick and LUC, 2002; Swanwick et al., 2007), and emphasises why places are special in terms of their character and distinctiveness. While attempting to minimise undue subjectivity, LCA does not make any pretence at being guided by public preference. Rather, it is a Delphi (expert) method of meeting public preferences by proxy whereby the general framework of the assessment process essentially substitutes for individual preferences.

According to Santos (1998), this move towards character assessment, and the abandoning of research to further evaluation, has left a void for evaluating trade-offs between development benefits and landscape quality. This void has most recently been filled by environmental economics; that is, the transition from evaluation to valuation.

34.3.1 The economic valuation of landscapes

LCA guidance talks of landscape as having economic value, 'providing the context for economic activity and often being a central factor in attracting business and tourism' (Swanwick and LUC, 2002). Such revealed activity does not, however, represent a landscape's total economic value, as public preferences for landscape are very rarely transacted in a market place. This means that a large proportion of the value for users and non-users of landscape is simply not accounted for in planning.

Improvements in environmental valuation techniques, and a growing body of revealed and stated preference studies, provide some data to substantiate the process of landscape planning. These methods side-step the problems of evaluation of ordinal scales by allowing subjectivity to be translated into a numeraire (money). The mean stated preference or willingness to pay in money terms determines what is and is not important, and as long as a wide enough sample of the public is obtained, the issue of objectifying subjectivity is addressed. It is important to note, that such economic valuation is not typically concerned with the total or absolute value of a landscape. Instead it is only concerned with a) changes in the economic value of given landscape types due to some policy intervention or other change (such as a windfarm), or b) the economic value of a given landscape type relative to an alternative – for example draining a wetland and replacing it with arable farming (Swanwick et al., 2007).

But these advances have not been without criticism directed at the potential biases in preference elicitation using neoclassical methods. These criticisms vary in the extent to which they challenge the underlying theoretical validity (Spash, 1998; Rosenberger *et al.,* 2001), and the extent to which they advance plausible alternatives for evaluating trade-offs (Toman, 1998). Theoretical criticism tends to lead to the use of alternative deliberative of multicriteria methods as aids to decision making. However, the theoretical validity of these methods appears to be no more robust than that claimed by neoclassical methods.

Revealed preferences are closer to conventional markets in that these methods rely on some related complementary market (e.g. travel behaviour or property investment decisions) as a basis for inferring something about proximate landscape values of interest. The principal methods in the revealed preference category are the travel cost method and hedonic pricing. The mechanics of applying these are detailed in Garrod and Willis (1999). Neither of these techniques, however, is sufficiently discriminating of the detail that one might expect in landscape planning. Being based on complementary markets (i.e. travel and housing) they are only good for revealing preferences where those complements are present. In other words, only use values are considered, and this is a significant weakness, as any of the passive motives that may be held for landscapes by people who never go near them are simply not counted. Since these motives can be extremely important for iconic landscapes (e.g. the Scottish Highlands) it is important to consider techniques that can take them into account.

This problem can be addressed using stated preference methods; contingent valuation (CV) and choice experiments, which are essentially means of eliciting a willingness to pay for an environmental change from a selection of the general public (Alberini & Kahn, 2006).

Aside from the ability to quantify non-use preferences, a considerable advantage in using a stated preference method is its flexibility relative to revealed preferences. Using a survey and appropriate devices such as photos and montages, one can simply construct hypothetical landscape scenarios around a specific landscape or its composite features and elicit direct statements of welfare (or willingness to pay).

This hypothetical nature is both a strength and a weakness, and a major issue in the design of stated preference studies is the nature of what the respondent is asked to consider directly.

In the UK and Ireland a range of landscape types has been valued using stated preference approaches, mainly Environmentally Sensitive Areas. Bullock and Kay (1997) considered landscape change in the Southern Uplands in terms of heather and tree coverage as a result of grazing intensity. Garrod & Willis (1995) and Willis & Garrod (1993) valued changes in the South Downs ESA and Yorkshire Dales ESA respectively. The first study considered traditional farming and historic features; the second study asked respondents to choose and value their favourite landscape (abandoned, semi-intensive, planned, conserved, sporting and today's) as depicted in photo-montages. Campbell (2007) applied a discrete-choice experiment to estimate the economic benefits associated with rural landscape improvements in Ireland, while Hanley et al. (2008) valued changes in woodland cover in two UK National Parks, the Trossachs and the Lake District.

While for some people placing a monetary value on environmental goods is morally unacceptable, it does allow individual members of society to express their preferences for environmental goods such as landscapes in a convenient way that can then be taken account of in the decision-making process. Indeed it has been argued that this monetary expression of preference may in fact be the most effective way of introducing an element of social choice into economic development decisions (Garrod, 1996). As noted by Swanwick et al. (2007) while there are difficulties that arise in applying economic valuations to landscape, these can only be completely avoided by declining to apply these techniques altogether. Not only would this fly in the face of current practice, it would risk landscape issues being left out of important decision-making processes.

It is also important to note that landscape is a good area for eliciting public preferences through valuation as it is within the experience of respondents and of relevance to them. By contrast, for complex ecological considerations where irreversible effects may occur, an expert led approach may be more appropriate.

34.4 Further research

It is not the role of this research to consider the practical issues that would have to be tackled were the planning system to adopt such an approach on a broad scale. While it might be interesting to speculate on the resistance to what could be seen as an assault on 'expert knowledge' in the matters of landscape planning, it is of greater relevance to consider the key challenges in respect of windfarms that will be faced by planning professionals in the next few years. This can then highlight important research needs in the field of landscape valuation.

While there is clearly an immediate need for primary landscape valuation studies to verify the actual disamenity impacts of windfarms, it would appear that for onshore wind, with increasing numbers of applications for windfarms in the areas of greatest potential, of growing importance will be the issue of cumulative landscape and visual impacts.

As mentioned in Chapter 5, guidance from Scottish Natural Heritage (2005) gives an example of two windfarms either side of a valley, suggesting that taken together, the combined impact may be greater than the sum of the two individual impacts. While intuitively it could be argued that the two together have an increased impact, it could be expected that there might in fact be a 'diminishing marginal disutility' in terms of valuing the successive changes to the landscape.

While it has in fact been observed from previous studies that people experience diminishing marginal effects of both gains and losses (Kahneman and Tversky, 1979; Knetsch, 2007), there is as yet no evidence either way specific to wind farm installations. Undertaking research into cumulative impacts via landscape valuation studies would bring much to a debate that is still characterized by a lack of objective evidence.

35.0 Concluding remarks

Government, be it in Brussels, Westminster or Edinburgh, sets both the incentive mechanisms and targets for renewable energy, on the basis that the former should lead to the achievement of the latter. However, there are a number of socio-economic constraints specific to certain renewable energy technologies that threaten this assumption.

The core argument of this thesis is that a better understanding is needed of these barriers to the development of renewable energy in the UK, in order that targets can be achieved, and achieved in an efficient manner. This theme runs through all four papers, and in juxtaposing perennial energy crops against wind power, illustrates the issues that affect renewable energy technologies (and associated inputs) at different stages in their development.

For perennial energy crops, which for farmers represent a novel crop with associated uncertainties, the investigation is essentially focused on private costs and benefits, from the farmer's point of view. The research focuses on understanding how the theoretical benefits, in terms of financial return, can most cost-effectively be realised, and how the real and perceived costs can best be tackled. A number of key constraints are identified, and findings of clear policy relevance, which could help targets to be achieved at least cost, are presented.

For wind, from the private perspective, the benefits already outweigh the costs as can be seen from the large number of planning applications that have been submitted by developers. The technology is proven and well understood, and the analysis is therefore on the wider societal costs and benefits. A framework for assessment is developed which illustrates the potential to deliver, from the societal perspective, a more cost-effective deployment of onshore windpower in the UK

36.0 References

Aarts, H., Verplanken, B., van Knippenberg, A., 1998. Predicting behaviour from actions in the past: Repeated decision making or matter of habit? Journal of Applied Social Psychology, 28, 1355-1374.

AgraCeas, 2003. Mid-term evaluation of the Rural Development Plan for Wales. Final report for Welsh European Office.

Ajzen, I., 1985. From intentions to action: A theory of planned behaviour. In Kuhl, J., Beckman, J. (Eds.), Action control: From cognitions to behaviours (pp.11-39). Springer, New York.

Ajzen, I., 1991. The theory of planned behaviour, Organizational Behaviour and Human Decision Processes, 50, 179-211.

Ajzen, I. & Fishbein, M., 1980. Attitudes, Personality and Behaviour, Open University Press, Milton Keynes.

Alberini, A., Kahn, J.R.(Eds), 2006. Handbook on Contingent Valuation, Edward Elgar, Cheltenham.

Appleton, J., 1975. Landscape evaluation: the theoretical vacuum. Transactions of the Institute of British Geographers, No 66, 120-123.

Armitage, C., Conner, M., 2001. Efficacy of the Theory of Planned Behaviour: A meta-analytic review, British Journal of Social Psychology, 40, 471-499.

Austin, E. J., Deary, I. J., Willock, J., 2001. Personality and intelligence as predictors of economic behaviour in Scottish farmers. European Journal of Personality 15, 123-127.

Bagozzi, R., 1992. The self-regulation of attitudes, intentions and behaviour, Social Psychology Quarterly, 55, 178-204.

Bagozzi, R, Kimmel, S., 1995., A comparison of leading theories for the prediction of goal-directed behaviours, British Journal of Social Psychology, 34, 437-461.

Bandura, A, 1977a. Self-efficacy mechanism in human agency, American Psychologist, 37, 122-147.

Bandura, A, 1977b. Self-efficacy: Toward a unifying theory of behaviour change, Psychological Review, 84, 191-215.

Beedell, J. & Rehman,T., 1999. Explaining farmers' conservation behaviour: Why do farmers behave the way they do? Journal of Environmental Management, 57, 165-176.

Beedell, J. & Rehman, T., 2000. Using social-psychology models to understand farmers' conservation behaviour. Journal of Rural Studies 16, 117-127.

Bergson, A., 1938. A reformulation of certain aspects of welfare economics, Quarterly Journal of Economics, 52, 314-344.

Boulanger, S., Gilman, A., Deaville, J., 1999. Framers' stress survey. Institute of Rural Health, Powys.

Bowler, I., 1979. Government and agriculture: a spatial perspective. Longman, London.

Brotherton, I., 1989. Farmer participation in voluntary land diversion schemes: some observations from theory. Journal of Rural Studies 5, 299-304.

Brotherton, I., 1991. What limits participation in ESAs? Journal of Environmental Management 32, 241-249.

Bullock, C. and Kay, J., 1997. Preservation and change in the upland landscape: the public benefits of grazing management. Journal of Environmental Planning and Management, 40, 315-334.

Burall, P., 2004. Putting wind turbines in their place, Town and Country Planning, 73(2), pp. 60-63.

Burton, R. J. F., 2004. Reconceptualising the 'behavioural approach' in agricultural studies: a socio-psychological perspective. Journal of Rural Studies 20, 359-371.

Campbell, D., 2007. Willingness to Pay for Rural Landscape Improvements: Combining Mixed Logit and Random-Effect Models, Journal of Agricultural Economics 58, 467-483.

Conner, M., Black, K., Stratton, P., 1998. Understanding drug compliance in a psychiatric population: An application of the theory of planned behaviour, Psychological Health Medicine, 3, 337-344.

Connor,M., Armitage, C., 1998. Extending the theory of planned behaviour: A review and avenues for further research, Journal of Applied Social Psychology, 28, 1429-1464.

CPRE, 2005. 'Wind farm free-for-all threatens countryside', News release, Campaign to Protect Rural England, 28 September 2005. Available at http://www.cpre.org.uk/news/view/98 (accessed February 2007)

Defra, 2006. Research to understand and model the behaviour and motivations of farmers in responding to policy changes (England) - Application and impact of the Single Payment Scheme: a Theory of Planned Behaviour analysis. Project Report no. 6, Research project EPES 0405/17.

Devine-Wright, P., 2005. Beyond NIMBYism: towards an Integrated Framework for Understanding Public Perceptions of Wind Energy. Wind Energy, 8, 125-139.

DTI, 2002. New and renewable energy: prospects for the 21st century, Department of Trade and Industry, London.

Eagly, A. Chaiken, S., 1993. The Psychology of Attitudes, Harcourt Brace Jovanovich, San Diego.

Edwards-Jones, G., 2006. Modelling farmer decision-making: concepts, progress and challenges. Animal Science, 82, 783-790.

Elliot, D., 1997. Energy, Society and Environment, Routledge, London,

Ellis, G., Barry, J. and Robinson, C., 2007. Many Ways To Say "No" – Different Ways To Say "Yes": Applying Q-Methodology To Understand Public Acceptance Of Wind Farm Proposals, Journal of Environmental Planning and Management, Vol. 50, No. 4, p. 517-551

Etherington, J.R., 2006. The case against wind farms. Countryside Guardian, available at: http://www.countryguardian.net/Case%20document.htm (accessed January 2007)

Fishbein, M., Ajzen, I., 1975, Belief, Attitude, Intention and Behaviour: An Introduction to Theory and Research, Addison-Wesley, Reading, MA.

Fisher, D. K., Norvell, J., Sonka, S., Nelson, M. J., 2000. Understanding technology adoption through systems dynamics modelling: implications for agribusiness management, International Food and Agribusiness Review, vol.3, no.3, 281-296.

Fliegel, F., 1993. Diffusion Research in Rural Sociology, Greenwood, Westport, USA.

Gaes, G. G., Kalle, R. J., Tedeschi, J. I,. 1978. Impression management in the forced compliance situation: Two studies using the bogus pipeline. Journal of Experimental Social Psychology, 9, 491-501.

Garrod, G., 1996. Valuing Environmental Goods in the Countryside, in Allanson, P. and Whitby, M. (Eds), 1996. The Rural Economy and the British Countryside, Earthscan, London.

Garrod, G. D. and Willis, K. G., 1995. 'Valuing the Benefits of the South Downs Environmentally Sensitive Area', Journal of Agricultural Economics 46 (2), pp160-173

Garrod, G. & Willis, K., 1999. Economic valuation of the environment: methods and case studies. Edward Elgar, Cheltenham, UK.

Guerin, L. J., Guerin, T. F., 1994. Constraints to the adoption of innovations in agricultural research and environmental management: a review. Australian Journal of Experimental Agriculture 34, 549-571.

Haggett, C., 2004. Tilting at Windmills? The Attitude-Behaviour Gap in Renewable Energy Conflicts. Final Report, ESRC Environment and Human Behaviour: New Opportunities Programme. http://www.psi.org.uk/ehb/docs/finalreport-Haggett.pdf (accessed April 2007)

Hanley, N., Spash, C., 2003. Cost-Benefit Analysis and the Environment, Edward Elgar, Cheltenham, UK.

Hanley, N., Ready, R., Colombo, S., Watson, F., Stewart, M., Bergmann, E. A., 2008. The impacts of knowledge of the past on preferences for future landscape change. Stirling Economics Discussion Paper, 2008-05.

Hessing, D. J., Elffers, H., Weigel, R. H., 1988. Exploring the limits of self-reports and reasoned action: An investigation into the psychology of tax evasion behaviour, Journal of Personality and Social Psychology, 54, 405-413.

HMSO, 2000. The Electricity Works (Environmental Impact Assessment) (Scotland) Regulations (2000). Available at http://www.opsi.gov.uk/legislation/scotland/ssi2000/20000320.htm (accessed November 2006)

Hoffman, S.J., Pytlikzillig, L.M., Lynne, G.D., Tomkins, A., Hu., Q.S., Hayes, M.J., Waltman, W.J., Hubbard, K.G., Wilhite, D.A., Improving scientific understanding of climate forecast and information usage among agricultural producers: the social psychology theory of planned behaviour, Bulletin of the American Meteorological Society, August 9, 2004.

Jackson, E. L., Quaddus, M., Islam, N., Stanton, J., 2006. Hybrid vigour of behavioural theories in the agribusiness research domain. Is it possible? Journal of International Farm Management, Vol 3, No. 3, July 2006.

Jones, G. E., 1963. The diffusion of agricultural innovations. Journal of Agricultural Economics 15: 387-409.

Kahn, R., 2000. Siting struggles: the unique challenge of permitting renewable energy power plants. The Electricity Journal, Vol. 13, p21-33.

Kahnemanm, D., and Tversky, A., 1979. Prospect theory: an analysis of decisions under risk. Econometrica 47, 263-291.

Kaiser, F., Woelfing, S., Fuhrer, U., 1999. Environmental attitude and ecological behaviour, Journal of Environmental Psychology

Khan, J., 2003. Wind power planning in three Swedish municipalities, Journal of Environmental Planning & Management 46 (4), 563-81.

Knetsch, J.L., 2007. Biased valuations, damage assessments, and policy choices: The choice of measure matters. Ecological Economics, 63 (4), 684 - 689

Krohn, S. & Damborg, S., 1999. On public attitudes towards wind power. Renewable Energy, 16 (1-4) pp.954-960

Landscape Institute, 1999. Landscape Institute Advice Note 01/99: Guidelines for Landscape and Visual Impact Assessment, London.

Landscape Institute & Institute of Environmental Assessment (LI-IEA), 1995. Guidelines for Landscape and Visual Impact Assessment. E. & F.N. Spon, London.

Landscape Institute & Institute for Environmental Management & Assessment (LI-IEMA), 2002. Guidelines for Landscape and Visual Impact Assessment, 2nd Edition. Spon Press, London.

Layard, R., Mayraz, G., Nickell, S., 2008. The marginal utility of income, Journal of Public Economics 92, Issues 8-9, 1846-1857.

Lichfield, N.,1971. Cost-benefit analysis in planning: A critique of the Roskill Commission. Regional Studies 5, 157-183.

Lynne, G., Casey, C., Hodges, A., Rahmani, M., 1995. Conservation technology adoption decisions and the theory of planned behaviour, Journal of Economic Psychology, 16, 581-598.

Manstead, A., Van Eekelen, S., 1998. Distinguishing between Perceived Behavioural Control and Self-Efficacy in the domain of academic achievement intentions and behaviours, Journal of Applied Social Psychology, 28, 1375-1392.

Mathijs, E., 2003. Social capital and farmers' willingness to adopt countryside stewardship schemes. Outlook on Agriculture 32, 13-16.

Mattison, E.H.A., Norris, K., 2007. Intentions of UK farmers toward biofuel crop production: implications for policy targets and land use change, Environmental Science and Technology 41 (16), 5589-5594.

McGregor, M., Willock, J., Deary, I., 1995. Farmer stress. Farm Management 9, 57-65.

Morris, C., Potter, C., 1995. Recruiting the new conservationists: farmers' adoption of agri-environmental schemes in the UK. Journal of Rural Studies 11, 51-63.

Morrison, D., Gillmore, E., Simpson, E., Wells, E., 1996. Children's decisions about substance use: An application and extension of the theory of reasoned action, Journal of Applied Social Psychology, 26, 1658-1679.

Neupane, R. P., Sharma, K. R., Thapa, G.B., 2002. Adoption of agroforestry in the hills of Nepal: a logistic regression analysis. Agricultural Systems 72, 177-196.

Nkonya, E., Schroeder, T., Norman, D., 1997. Factors affecting adoption of improved maize seed and fertilizer in northern Tanzania. Journal of Agricultural Economics 48, 1-12.

Norman, P., Conner, M, Bell, R., 1999. The theory of planned behaviour and smoking cessation, Health Psychology, 18, 89-94.

Pasqualetti, M. J., Gipe, P. & Righter, R. W. (Eds.), 2002. Wind Power in View: Energy Landscapes in a Crowded World, Academic Press, San Diego.

Potter, C., Gasson, R., 1998. Farmer participation in voluntary land diversion schemes: some predictions from a survey. Journal of Rural Studies 4, 365-375.

Price, C., 1993. Applied Landscape Economics: a Personal Journey of Discovery, Journal of Environmental Planning and Management vol. 36, 1 pp 51-63

Ramblers Association Scotland, 2005. Submission to RSE Inquiry on Issues for Scotland's Energy Supply, July 2005. Available at http://www.royalsoced.org.uk/enquiries/energy/evidence/Ramblers_Scotland.pdf (accessed October 2006)

Revell, B. and Oglethorpe, D., 2003. Decoupling and UK Agriculture: A whole farm approach. An appraisal of the impact on the livestock sector, commissioned by Defra.

RCEP, 2000. Energy- the changing climate. Royal Commission on Environmental Pollution, London.

Richard, R., de Vries, N., van der Plight, J., 1998. Anticipated regret and precautionary sexual behaviour, Journal of Applied Social Psychology, 28, 1411-1428.

Righter, R.W., 1996. Wind Energy in America: A History. Norman, University of Oklahoma Press.

Rogers, E. M., 1995. Diffusion of Innovations, 4th ed. The Free Press, New York.

Rogers, E. M., 2003. Diffusion of Innovations, 5th ed. The Free Press, New York.

Rosenberger, R., Peterson, G, Clarke, A. and Brown, T., 2001. Dispositions for Lexicographic Preferences of Environmental Goods: Integrating Economics, Psychology and Ethics. Research Paper 2001-12, Regional Research Institute & Division of Resource Management, West Virginia University.

http://www.rri.wvu.edu/pdffiles/rosenberger2001-12.pdf (accessed January 2007)

Ryan, B., Gross, N. C., 1943. The diffusion of hybrid seed corn in two Iowa communities, Rural Sociology, Vol. 8, No. 1, 15-24.

Sagoff, M., 1988. The Economy of the Earth, Cambridge University Press, Cambridge.

Santos, J.M., 1998. The economic valuation of landscape change: Theory and policies for land use and conservation, Edward Elgar, Cheltenham, UK.

Scottish Executive, 2007. Scottish Planning Policy 6: Renewable Energy. http://www.scottishexecutive.gov.uk/Resource/Doc/171491/0047957.pdf (accessed April 2007)

Sheikh, A. D., Rehman, T., Yates, C. M., 2003. Logit models for identifying the factors that influence the uptake of new 'non-tillage' technologies by farmers in the rice-wheat and the cotton-wheat farming systems of Pakistan's Punjab. Agricultural Systems 75:79-95.

Sherrington, C., Bartley, J. and Moran, D., 2008. Farm-level constraints on the domestic supply of perennial energy crops in the UK. Energy Policy 36, 2504-2512.

Short, L., 2002. Wind power and English landscape identity, in Pasqualetti, M. J., Gipe, P. & Righter, R. W. (Eds.), 2002. Wind Power in View: Energy Landscapes in a Crowded World, Academic Press, San Diego.

Smith, E. and Marquez, M., 2000. The other side of the NIMBY syndrome. Society and Natural Resources, Vol. 13, p273-280

Scottish Natural Heritage, 2005. Cumulative Effect of Windfarms: Guidance, Version 2 revised 13.04.05.

Solano, C., Leon, H., Perez, E., Herroro, M., 2003. The role of personal information sources on the decision-making process of Costa Rican dairy farmers. Agricultural Systems 76, 3-18.

Spash C.L., 1998. Investigating individual motives for environmental action: Lexicographic preferences, beliefs and attitudes, in Lemons, J., Westra, L. and Goodland, R.(Eds) Ecological Sustainability and Integrity: Concepts and Approaches. Kluwer Academic Publishers: Netherlands. pp. 46-62.

Strachan, P.A. & Lal, D., 2004. Wind energy policy, planning and management practice in the UK: hot air or a gathering storm?, Regional Studies 38 (5): 551-571.

Strachan, P.A., Lal, D and von Malmborg, F., 2006. The evolving UK wind energy industry: critical policy and management aspects of the evolving research agenda. European Environment, Vol. 16, p1-18

Sustainable Development Commission, 2005. Wind power in the UK: A guide to the key issues surrounding onshore wind power development in the UK. London

Swanwick, C and Land Use Consultants, 2002. Landscape Character Assessment - Guidance for England and Scotland CAX 84. Countryside Agency, Cheltenham and Scottish Natural Heritage, Edinburgh. 84p.

Swanwick, C., Hanley, N., Termansen, M., 2007. Scoping Study on Agricultural Landscape Valuation, Report to Defra, October 2007.

Toman, M., 1998. Sustainable Decision-making: The State of the Art from an Economics Perspective. Discussion Paper 98-39, Resources for the Future, Washington D.C.

http://www.rff.org/Documents/RFF-DP-98-39.pdf (accessed February 2007)

Trumbo, C., O'Keefe, G., 2001. Intention to conserve water: Environmental values, planned behaviour, and information effects. A comparison of three communities sharing a watershed, Society and Natural Resources, 14, 889-899.

Tutkun, A., Lehmann, B., Schmidt, P., 2006. Explaining the conversion to organic farming of farmers of the Obwalden Canton, Switzerland – Extension of the Theory of Planned Behaviour within a structural equation modeling approach. Paper prepared for the 80th Annual Conference of the Agricultural Economics Society, 30th and 31st March 2006, Paris-Grignon.

University of Cambridge, 2005. Farm level economic impacts of energy crop production, Final Report to Defra, August 2005.

University of Newcastle, 2002. Visual Assessment of Windfarms Best Practice. Scottish Natural Heritage Commissioned Report F01AA303A

Van der Plight, J., de Vries, N., 1998. Belief importance in expectancy-value models of attitudes, Journal of Applied Social Psychology, 28, 1339-1354.

Vanslembrouck I.; Van Huylenbroeck G.; Verbeke W., 2002. Determinants of the willingness of Belgian farmers to participate in agri-environmental measures. Journal of Agricultural Economics 53, 489-511.

Vincent, P., Peplau, L, Hill, C., 1998. A longitudinal application of the theory of reasoned action to women's career behaviour, Journal of Applied Social Psychology, 18, 761-778.

Wallace, M. T., Moss, J. E., 2002. Farmer decision-making with conflicting goals: a recursive strategic programming analysis. Journal of Agricultural Economics 53: 82-100.

Willis, K.G. and Garrod, G.D., 1993. Valuing Landscape: A Contingent Valuation approach. Journal of Environmental Management, 37, 1-22.

Willock, J., Deary, I.J., Edwards-Jones, G., Gibson, G.J., McGregor, M.J., Sutherland, A., Dent, J.B., Morgan, O. and Grieve, R, 1999a. The role of attitudes and objectives in farmer decision making: Business and environmentally oriented behaviour in Scotland. Journal of Agricultural Economics 50: 286-303.

Willock, J., Deary, I. J., McGregor, M. M., Sutherland, A., Edward-Jones, G., Dent, B., Grieve, R., Gibson, G., Austin, E.,1999b. Farmers' attitudes, objectives, behaviors, and personality traits: The Edinburgh study of decision making on farms. Journal of Vocational Behavior, 54, 5-36.

Wilson, G. A., 1997. Factors influencing farmer participation in the Environmentally Sensitive Areas Scheme. Journal of Environmental Management 50, 67-93.

Wolsink, M., 2007a. Wind power implementation: The nature of public attitudes: Equity and fairness instead of 'backyard motives'. Renewable & Sustainable Energy Reviews, 11, 1188-1207.

Wolsink,M., 2007b. Planning of renewables schemes: Deliberative and fair decision-making on landscape issues instead of reproachful accusations of non-cooperation Energy Policy 35, 2692 - 2704

WWF-UK, 2003. WWF-UK policy position on wind power. Available at http://www.wwf.org.uk/filelibrary/pdf/windpowerposition.pdf (accessed November 2006)

Wilson, G.A., 1997. Factors influencing farmer participation in the Environmentally Sensitive Areas Scheme. Journal of Environmental Management 50, 67-93.

Wolsink, M., 2007a. Wind power implementation: The nature of public attitudes: Equity and fairness instead of "backyard motives". Renewable & Sustainable Energy Reviews, 11, 1188-1207.

Wolsink, M., 2007b. Planning of renewables schemes: Deliberative and fair decision-making on landscape issues instead of reproachful accusations of non-cooperation. Energy Policy 35, 2692 - 2704

WWF-UK, 2001. WWF-UK policy position on windfarms. Available at http://www.wwf.org.uk/filelibrary/[illegible] (accessed November 2006)

A.1.0 Postal Questionnaire

SAC

insert ref no.

Section 1: Information about your farm business ***(By this we mean your major holding)***

Please circle or tick as appropriate.

1.1	Is your farm	Tenanted	Owned outright	Partly tenanted/ Partly owned		
1.2	Please tick the box that best describes your farm	Specialist dairy	☐	Specialist cereals	☐	
		Beef and/or sheep	☐	General cropping (arable)	☐	
		Pigs and/or poultry	☐	Other (please specify below)	☐	
		Mixed arable and livestock	☐			
1.3	What is the total area of your farm					(ha)
1.4	Which of the following approximately describes your farmland type	All lowland	Mostly lowland	Half and half	Mostly upland	All upland
1.5	How much of your farm income is from environmental schemes?	Less than 5%	Around 10%	Around 20%	Higher than 20%	
1.6	How much of your total income is made up from the Single Farm Payment	Less than 40%	Around half	More than half		
1.7	Please state how many regular farm workers, including family members, are employed on your farm	Full time	☐	Part time	☐	

Section 2: Current energy crop levels and future plans
(Please circle or tick as appropriate)

2.1	Are you currently growing SRC Willow on your farm?	Yes	No
2.2	Are you currently growing Miscanthus on your farm?	Yes	No

If you are currently growing SRC Willow or Miscanthus, please go to Q 2.3.
If you are **not** currently growing SRC Willow or Miscanthus, please go to Q 2.6

2.3	Please indicate the current area of SRC Willow and/or Miscanthus on your farm	SRC Willow	(ha)	Miscanthus	(ha)

	Statement	Certainly not	Probably not	Unsure	Probably	Certainly
2.4	Are you intending to plant more SRC Willow on your farm in the next 5 years?	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
2.5	Are you intending to plant more Miscanthus on your farm in the next 5 years?	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$

Now please go to Q 2.8

Please answer Q 2.6 and Q 2.7 if you are **not** already growing SRC Willow or Miscanthus

	Statement	Certainly not	Probably not	Unsure	Probably	Certainly
2.6	Are you intending to plant SRC Willow on your farm in the next 5 years?	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
2.7	Are you intending to plant Miscanthus on your farm in the next 5 years?	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$

Please outline any changes that you foresee to the area of SRC Willow and/or Miscanthus on your farm in the next 5 years. If no relevant changes please leave blank

2.8		Likely to cease production (tick if applicable)	Likely increase in planted area (state as hectares)	Likely reduction of planted area (state as hectares)	Likely to start production (state as hectares)
2.9	SRC Willow	☐	(ha)	(ha)	(ha)
2.10	Miscanthus	☐	(ha)	(ha)	(ha)

Section 3: Short Rotation Coppice (SRC) Willow

	Statement	Very difficult	Difficult	Unsure	Easy	Very easy
3.1	How difficult would it be to grow SRC Willow on your farm in the next 5 years?	☐$_1$	☐$_2$	☐$_3$	☐$_4$	☐$_5$

How important are the following to you?

	Statement	Unimportant	Not very important	No opinion	Important	Very important
3.2	Getting a high gross margin from farm activities	☐$_1$	☐$_2$	☐$_3$	☐$_4$	☐$_5$
3.3	Having a secure income from farm activities	☐$_1$	☐$_2$	☐$_3$	☐$_4$	☐$_5$
3.4	Choosing activities that fit in with my current cropping plans	☐$_1$	☐$_2$	☐$_3$	☐$_4$	☐$_5$
3.5	Choosing activities that give me greater stability of income	☐$_1$	☐$_2$	☐$_3$	☐$_4$	☐$_5$
3.6	Choosing activities for which the paperwork is easy	☐$_1$	☐$_2$	☐$_3$	☐$_4$	☐$_5$
3.7	Avoiding damage to field drains	☐$_1$	☐$_2$	☐$_3$	☐$_4$	☐$_5$
3.8	Maintaining the flexibility of the farm business	☐$_1$	☐$_2$	☐$_3$	☐$_4$	☐$_5$
3.9	Helping to tackle climate change through farm activities	☐$_1$	☐$_2$	☐$_3$	☐$_4$	☐$_5$
3.10	Growing energy crops for local or on-farm use	☐$_1$	☐$_2$	☐$_3$	☐$_4$	☐$_5$
3.11	Knowing the likely costs and returns of a farm activity	☐$_1$	☐$_2$	☐$_3$	☐$_4$	☐$_5$
3.12	Reducing the time I spend on farming activities	☐$_1$	☐$_2$	☐$_3$	☐$_4$	☐$_5$
3.13	Maintaining a regular cashflow	☐$_1$	☐$_2$	☐$_3$	☐$_4$	☐$_5$

Do you agree or disagree with the following statements?

	Statement	Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
3.14	Choosing to plant (further) SRC Willow on my farm in the next five years would be a good decision	☐$_{-2}$	☐$_{-1}$	☐$_0$	☐$_1$	☐$_2$
3.15	SRC Willow will give a high gross margin	☐$_{-2}$	☐$_{-1}$	☐$_0$	☐$_1$	☐$_2$
3.16	Growing SRC Willow to contract will give me greater income security	☐$_{-2}$	☐$_{-1}$	☐$_0$	☐$_1$	☐$_2$

	Statement	Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
3.17	Growing SRC Willow fits in with my current cropping plans	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
3.18	Growing SRC Willow to contract will give me greater stability of income	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
3.19	It is easy to do the paperwork required to grow SRC Willow to contract	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
3.20	SRC Willow roots will damage field drains	☐$_{2}$	☐$_{1}$	☐$_{0}$	☐$_{-1}$	☐$_{-2}$
3.21	Growing SRC Willow will reduce the flexibility of the farm business	☐$_{2}$	☐$_{1}$	☐$_{0}$	☐$_{-1}$	☐$_{-2}$
3.22	Growing SRC Willow is a good way for farmers to help tackle climate change	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
3.23	SRC Willow could be a good source of energy for local or on-farm use	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
3.24	The likely costs and returns of SRC Willow are easy to calculate	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
3.25	Growing SRC is a good opportunity to reduce the time spent on farming activities	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
3.26	Growing SRC Willow will disrupt my cashflow	☐$_{2}$	☐$_{1}$	☐$_{0}$	☐$_{-1}$	☐$_{-2}$
3.27	People whose opinions I value think I should plant SRC Willow on my farm in the next five years	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$

	Question	Not at all confident	Not very confident	Don't know	Confident	Very confident
3.28	How confident are you of being able to grow SRC Willow on your farm in the next 5 years?	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$

Listed below are a number of groups who might advise on whether or not you should grow SRC Willow on your farm in the next five years?
Do you think they would approve or disapprove of you growing SRC Willow?

		Strongly Disapprove	Disapprove	Unsure	Approve	Strongly Approve
3.29	Farmers clubs	☐	☐	☐	☐	☐
3.30	Existing SRC growers	☐	☐	☐	☐	☐
3.31	Other farmers	☐	☐	☐	☐	☐
3.32	SRC producer groups	☐	☐	☐	☐	☐
3.33	Power companies	☐	☐	☐	☐	☐
3.34	Farming press	☐	☐	☐	☐	☐
3.35	Defra	☐	☐	☐	☐	☐
3.36	Biomass Energy Centre	☐	☐	☐	☐	☐
3.37	NFU	☐	☐	☐	☐	☐
3.38	Agronomist	☐	☐	☐	☐	☐
3.39	Own experience judgement	☐	☐	☐	☐	☐
3.40	Family	☐	☐	☐	☐	☐
3.41	Members of the public	☐	☐	☐	☐	☐

Section 4. Personal information and further farm business information

4.1	Are you	Male	Female		
4.2	In what year were you born?				
4.3	Which of these best describes your highest level of education?	Secondary	Technical college		University
4.4	Do you see yourself as an early adopter of technology in your area?	Yes	No		Don't know
4.5	Have you identified a successor to take over the farm	Yes	No		Maybe
4.6	To what extent are you involved in businesses run by farmers groups?	Not at all	Occasionally		At every opportunity
4.7	Please indicate the approximate annual value of your total sales of agricultural products	Less than £10,000	£10,000 to £50,000	£50,000 to £100,000	Over £100,000

4.8	Over the past three years has your farm made a profit or a loss?	Significant profit	Moderate profit		Break even		Moderate loss	Significant loss
4.9	Is your farm business in debt?	Not at all			Lightly			Heavily
4.10	Approximately what proportion of your total annual farm costs are 'fixed' costs?	Less than 10%	10-20%	21-30%	31-40%	41-50%	Over 50%	Don't know
4.11	What proportion of your annual income is obtained from the farm business	100%	About 75%		About 50%		About 25%	Below 25%

Would you follow the advice of the groups below in deciding whether or not to grow perennial energy crops such as SRC Willow or Miscanthus on your farm in the next five years?

		Very unlikely	Unlikely	Unsure	Likely	Highly likely
4.12	Farmers clubs	☐	☐	☐	☐	☐
4.13	Existing SRC/Miscanthus growers	☐	☐	☐	☐	☐
4.14	Other farmers	☐	☐	☐	☐	☐
4.15	SRC/Miscanthus producer groups	☐	☐	☐	☐	☐
4.16	Power companies	☐	☐	☐	☐	☐
4.17	Farming press	☐	☐	☐	☐	☐
4.18	Defra	☐	☐	☐	☐	☐
4.19	Biomass Energy Centre	☐	☐	☐	☐	☐
4.20	NFU	☐	☐	☐	☐	☐
4.21	Agronomist	☐	☐	☐	☐	☐
4.22	Own experience/judgement	☐	☐	☐	☐	☐
4.23	Family	☐	☐	☐	☐	☐
4.24	Members of the public	☐	☐	☐	☐	☐

Section 5: Miscanthus

	Question	Very difficult	Difficult	Unsure	Easy	Very easy
5.1	How difficult would it be to grow Miscanthus on your farm in the next 5 years?	☐$_1$	☐$_2$	☐$_3$	☐$_4$	☐$_5$

Do you agree or disagree with the following statements?

	Statement	Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
5.2	Choosing to plant (further) Miscanthus on my farm in the next five years would be a good decision	☐$_{-2}$	☐$_{-1}$	☐$_0$	☐$_1$	☐$_2$
5.3	Miscanthus will give a high gross margin	☐$_{-2}$	☐$_{-1}$	☐$_0$	☐$_1$	☐$_2$
5.4	Growing Miscanthus to contract will give me greater income security	☐$_{-2}$	☐$_{-1}$	☐$_0$	☐$_1$	☐$_2$
5.5	Growing Miscanthus fits in with my current cropping plans	☐$_{-2}$	☐$_{-1}$	☐$_0$	☐$_1$	☐$_2$
5.6	Growing Miscanthus to contract will give me greater stability of income	☐$_{-2}$	☐$_{-1}$	☐$_0$	☐$_1$	☐$_2$
5.7	It is easy to do the paperwork required to grow Miscanthus to contract	☐$_{-2}$	☐$_{-1}$	☐$_0$	☐$_1$	☐$_2$
5.8	Miscanthus roots will damage field drains	☐$_2$	☐$_1$	☐$_0$	☐$_{-1}$	☐$_{-2}$
5.9	Growing Miscanthus will reduce the flexibility of the farm business	☐$_2$	☐$_1$	☐$_0$	☐$_{-1}$	☐$_{-2}$
5.10	Growing Miscanthus is a good way for farmers to help tackle climate change	☐$_{-2}$	☐$_{-1}$	☐$_0$	☐$_1$	☐$_2$
5.11	Miscanthus could be a good source of energy for local or on-farm use	☐$_{-2}$	☐$_{-1}$	☐$_0$	☐$_1$	☐$_2$
5.12	The likely costs and returns of Miscanthus are easy to calculate	☐$_{-2}$	☐$_{-1}$	☐$_0$	☐$_1$	☐$_2$
5.13	Growing Miscanthus is a good opportunity to reduce the time spent on farming activities	☐$_{-2}$	☐$_{-1}$	☐$_0$	☐$_1$	☐$_2$
5.14	Growing Miscanthus will disrupt my cashflow	☐$_2$	☐$_1$	☐$_0$	☐$_{-1}$	☐$_{-2}$
5.15	People whose opinions I value think I should plant Miscanthus on my farm in the next five years	☐$_{-2}$	☐$_{-1}$	☐$_0$	☐$_1$	☐$_2$

Listed below are a number of groups who might advise on whether or not you should grow Miscanthus on your farm in the next five years?
Do you think they would approve or disapprove of you growing Miscanthus?

		Strongly Disapprove	Disapprove	Unsure	Approve	Strongly Approve
5.16	Farmers clubs	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
5.17	Existing Miscanthus growers	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
5.18	Other farmers	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
5.19	Miscanthus producer groups	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
5.20	Power companies	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
5.21	Farming press	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
5.22	Defra	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
5.23	Biomass Energy Centre	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
5.24	NFU	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
5.25	Agronomist	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
5.26	Own experience judgement	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
5.27	Family	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$
5.28	Members of the public	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$

	Question	Not at all confident	Not very confident	Don't know	Confident	Very confident
5.29	How confident are you of being able to grow Miscanthus on your farm in the next 5 years?	☐$_{-2}$	☐$_{-1}$	☐$_{0}$	☐$_{1}$	☐$_{2}$

Section 6: Comments

Please feel free to add any comments

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Farm-level constraints on the domestic supply of perennial energy crops in the UK

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ABSTRACT

There are a number of estimates of the land area that could potentially be dedicated to perennial energy crops such as short rotation coppice (SRC) willow and miscanthus in the UK, but little is known about how farmers will respond to the opportunities presented by these relatively novel crops. Perennial energy crops face competition from other, arguably more flexible, uses of farmland, and if not seen as attractive propositions to individual farmers, they will not be grown. Farmers' decisions are therefore a key constraint on potential supply. This paper reviews the policy background and considers whether policy is based on any consideration of likely supply response, before presenting outcomes of focus groups composed of farmers who already grow or are considering growing perennial energy crops. There appear to be a number of barriers to adoption. In addition to concerns over the security of contracts, the current high wheat price increases the opportunity cost of committing land to perennial energy crops. There are also worries about the impact of willow roots on field drains and the cost of returning the land to other uses. This paper outlines a number of issues of importance to policy makers and suggests future research needs.

1. Introduction

The twin concerns of climate change and energy security have increased attention on renewable energy. In the UK, these factors have combined with an agricultural reform process that has highlighted the need for farmers to diversify away from traditionally supported arable and livestock products. Accordingly, the UK Government has in recent years demonstrated an increasing enthusiasm for the use of biomass as a source of electricity, heat and transport fuel. The UK Biomass Strategy (Defra, 2007a) states the Government's intention to bring about a major expansion in both the supply and use of biomass in the UK, indicating that biomass will have a central role to play in meeting the EU target of 20% renewable energy by 2020 (Defra, 2007a).

While the UK Biomass Strategy proposes an increase in the use of biomass for heat, electricity and biofuels, beyond acknowledging the 10% minimum share of biofuels target for 2020 (Council of the European Union, 2007) it does not include specific targets for particular feedstocks or end uses. It does, however, outline what the UK Government considers to be the potential UK supply of biomass feedstocks up to 2020.

This paper will argue that for perennial energy crop feedstocks such as short rotation coppice (SRC) willow and miscanthus, the likely level of supply will be considerably below the theoretical potential unless a number of barriers to their adoption by farmers are overcome.

The paper adds to a growing literature on perennial energy crops and the development of biomass energy in the UK, Europe and beyond (Rosenqvist and Dawson, 2005; Skytte et al., 2006; Charles et al., 2007). While there has been much focus on techno-economic aspects and theoretical supply chain potential (Andersen et al., 2005; Ericsson and Nilsson, 2006; Styles and Jones, 2007), broad stakeholder opinion (Upham and Speakman, 2007), and wider public policy implications (Charles et al., 2007), relatively little is known about how individual farmers will choose to respond to the opportunities presented by these relatively novel crops. Strawson (2005), writing from the perspective of a farmer with land already committed to SRC willow, and at a time when returns from alternative activities were much lower than at present, offers a relatively upbeat assessment of the potential attractiveness of the crop. However, in the context of a significant and ongoing global rise in the price of agricultural commodities such as wheat (FAO, 2007), a changing agricultural policy landscape in the EU (European Commission, 2007), and a UK renewable energy support mechanism that is under review (DTI, 2007a), it is important to gain an up-to-date

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understanding of farmers' attitudes and behavioural intentions towards the adoption of perennial energy crops.

The paper is structured as follows. The next section outlines the framework for considering farm-level constraints, and is followed by an introduction to UK biomass resources. A number of estimates of the theoretical potential of perennial energy crops are discussed, and compared with the recent level of adoption. There follows an outline of the policies intended to stimulate the use of biomass in the energy mix, along with details of farm-level support for the cultivation of perennial energy crops. The results of a series of focus groups with farmers discussing adoption of perennial energy crops are then outlined, with consideration of the implications of the findings for policy makers.

2. Framework for considering farm-level constraints on the adoption of perennial energy crops

Perennial energy crops can be considered as a novel enterprise for UK farmers both in terms of their cultivation, and in their position at the interface between agricultural and energy policy. This brings a greater number of uncertainties than exist with conventional agricultural activities. Several authors have argued that uncertainty is a key barrier to the successful uptake of emerging renewable technologies such as bioenergy (Kemp et al., 1998; Foxon et al., 2005), principally because it hinders the fulfilment of entrepreneurial activities (Jacobsson and Bergek, 2004). In order for entrepreneurs to act, motivation needs to outweigh perceived uncertainty. Therefore, identifying dominant sources of uncertainty can deliver valuable insights for policy makers (Meijer et al., 2007).

In addition, many systems such as energy and agriculture are characterised by lock in and resistance to change (Unruh, 2000), through technological, institutional and social path dependency, resulting in a variety of barriers for new innovations such as energy crops and bioenergy (van der Laak et al., 2007). Much work has been done in the field of Strategic Niche Management (SNM) to identify what makes for a successful innovation, or to explain the failure of other innovations (van der Laak et al., 2007; Raven, 2005). The level of analysis in SNM is typically a series of projects such as pilot plants and demonstration plants, covering a substantial number of projects over periods up to 30 years. This yields useful insights for policy makers, and emphasises the importance of shaping expectations of stakeholders, building social networks, and of a good learning process (van der Laak et al., 2007). In addition, lessons for policy makers can be drawn from research into technological innovation in the energy sector. A key insight here is that identifying market barriers that stand in the way of widespread implementation of new technologies, and then designing ways to overcome these, while concurrently enhancing learning gains, are crucial to successful energy innovation (Sagar and van der Zwaan, 2006).

Thus the identification of barriers to farmer adoption of perennial energy crops, and how these may be overcome is of key importance to policy makers intent on a significant increase in the use of bioenergy in the UK.

For this study, the Theory of Reasoned Action (TORA) (Ajzen and Fishbein, 1980) and its extension the Theory of Planned Behaviour (TPB) (Ajzen, 1991) provide the conceptual framework for exploring farmers' attitudes and intentions in respect of the adoption of perennial energy crops. Both theories have been widely used in agricultural research to understand barriers and drivers to the adoption of new technologies and practices (Garforth et al., 2004; Beedell and Rehman, 2000) and to estimate the likely scale of adoption of particular activities (Mattison and Norris, 2007).

The first stage of the research involves using focus groups to gather a range of statements from farmers relating to their attitudes to the adoption of perennial energy crops. It is the findings from this first stage that are reported in this paper.

3. Potential biomass resources in the UK

There are a number of possible sources of biomass for energy in the UK, including forestry, wood waste, conventional agricultural crops such as wheat and oilseed rape, straw, perennial energy crops, and agricultural waste (RCEP, 2004: Defra, 2007a).

To increase available biomass, Defra (2007a) favours obtaining an additional 1 million dry tonnes of wood per annum from woodland and wood waste, more use of manures and slurries, and a substantial growth in uptake of perennial energy crops such as SRC willow and miscanthus. Of these sources, it is the anticipated change in levels of perennial energy crops that is most dramatic. The technical potential of energy crops is estimated to be 17.2 TWh[1] (1.48 Mtoe),[2] while current availability is 0.07–0.09 Mtoe (Defra, 2007a). Such an increase would represent an almost 20-fold increase in the level of supply, albeit from a low level.

To reach the technical potential of perennial energy crops by 2020 (Defra, 2007a), would require 350,000 hectares (ha) of land, which is roughly 6.5% of UK arable and set-aside land, assuming an average annual yield of 9 odt/ha[3] (Defra, 2007a). The Renewables Innovation Review (DTI, 2003b) suggests this is a realistic area once a number of constraints, including competition from other markets, are taken into account.

Defra expectations for perennial energy crops are somewhat lower than proposals from the Royal Commission on Environmental Pollution (RCEP) biomass report (RCEP, 2004). Focusing on the potential contribution of biomass towards a 60% reduction in UK CO_2 emissions by 2050 (RCEP, 2000), it recommends that by 2050 up to 16 Gigawatts (about 12%) of UK energy should come from biomass. To supply this, about 70 million tonnes of wood would be required per year. If derived from energy crops at an assumed average yield of 10 odt/ha/yr, this would need 7 million hectares.

However, assuming the availability of a certain amount of forestry material and straw, a scenario is outlined where the land required for energy crops would rise from 1 million hectares in 2020 to 5.5 million hectares in 2050 (RCEP, 2004).

Other estimates include an assumption by the Carbon Trust (2005) that 680,000 ha (roughly equal to set-aside) could be available for woody energy crops. This study notes that estimates of the land area that could be used for energy crops vary greatly, emphasising the somewhat arbitrary nature of their assumption (Carbon Trust, 2005).

The key feature of all these estimates is the assumptions about farmer behaviour. They take for granted that sufficient farmers will choose to grow perennial crops up to the level of the constraints that they identify. However, this assumption does not seem to be supported by experience to date.

Defra's Energy Crops Scheme, which provides establishment grants for SRC willow and miscanthus, along with support for developing SRC producer groups, had a number of objectives for the first period of the English Rural Development Programme (ERDP) (2000–2006). These included the planting, by 2006, of 16,700 ha of SRC and 5000 ha of miscanthus in England (ADAS, 2003). When the scheme closed to applications, in July 2006, only

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[1] Terrawatt hours (one terrawatt is a trillion, or 10^{12} W).

[2] Million tonnes of oil equivalent.

[3] Oven dried tonnes.

1180 ha of SRC and 3356 ha of miscanthus had been planted (Defra, 2006a), representing 20% of the target level. This does, however, mark an improvement over the uptake by the half-way point in 2003, where only 2% of the SRC target and 3% of the miscanthus target had been planted (ADAS, 2003).

More recently, there has been an increase in interest in the payments, with applications for planting in 2007 due to take the area of miscanthus to 12,627 ha, and SRC to 2600 ha in England (Defra, 2006a).

In Scotland, the area planted or approved for planting up until the end of 2006 is 300 ha. Current applications for planting in 2007 and 2008 amount to around 600 ha (SAC, 2007). In Northern Ireland, 400 ha of SRC have been planted or approved for planting to date, and a further 410 ha have been approved for the 2007 planting year (DARDNI, 2007), while in Wales there is currently 40 ha of SRC and 72 ha of miscanthus (Welsh Assembly Government, 2007).

The current total area of energy crops in the UK is 15,546 ha for SRC willow and miscanthus combined (Defra, 2007a).

4. Policies intended to stimulate the use of biomass in the UK energy mix

4.1. *Renewables Obligation*

The Renewables Obligation (RO) is the UK Government's key policy mechanism for increasing the proportion of electricity derived from renewable sources. Under the scheme, there is a mandatory requirement for UK electricity suppliers to source a growing percentage of electricity from eligible renewable generation capacity. Suppliers are required to produce evidence of their compliance with this obligation to the office of gas and electricity markets (OFGEM). Evidence can be via certificates, referred to as Renewable Obligation Certificates (ROCs), which are currently worth approximately £47/MWh (NFPA, 2007).The target is 10% of UK electricity from renewable sources by 2010, with an aspiration to reach 20% by 2020 (DTI, 2007a). When introduced in 2002, there was debate as to whether co-firing of energy crops[4] with coal should be eligible for receiving ROCs. It was decided that co-firing should be eligible, in order to stimulate the development of energy crop supply chains (DTI, 2006b, Ilex Energy Consulting, 2003), but with restrictions, intended to prevent co-firing swamping the market for ROCs. A 25% cap was placed on the proportion of a supplier's obligation that could be met from co-fired ROCs; from 2006 at least 75% of the biomass must be from energy crops; and co-firing would cease to be eligible by 2011.

However, the majority of co-firing has been of imported bio-wastes such as olive pits and palm kernels (IPA Consulting, 2006), while energy crops represent less than 0.3% by weight of all co-fired biomass.

In 2003, The Renewables Obligation (Amendment) Order Statutory Consultation noted that minimal planting of energy crops had taken place, with industry arguing that this was in part due to overly restrictive rules on co-firing in the Obligation; in particular that co-firing should be permitted only until 2011 (DTI, 2003a). It was therefore recommended that the requirement to co-fire a proportion of energy crops should be delayed from 2006 to 2009 to allow more time for planting and cropping (DTI, 2003a).

In addition, the date for co-firing to be phased out of the RO was postponed until 2016, and the energy crop requirements were relaxed (25% requirement in 2009, 50% in 2010 and 75% in 2011). Meanwhile the overall cap on co-firing was reduced (10% from 2006 and 5% from 2011) (DTI, 2006a).

The proposed changes were intended to enable the creation of a market for energy crops of up to 680,000 odt per annum, generating 1.26 TWh per annum, this being 75% of the 5% of the Obligation in the period 2011–16 (DTI, 2003a). By amending the start and end-dates for energy crop co-firing, it was intended to allow farmers three full cropping cycles for SRC planted in the spring of 2005 making this a much more attractive option in terms of establishing a market for energy crops (DTI, 2003a).

It was, however, argued at the time that extending the eligibility of co-firing would not provide the necessary stimulus to energy crop development, and that co-firing would likely displace investment in specialist energy crop combustion plants (Campbell Carr, 2003).

In the run up to the introduction of the 10% cap in April 2006, a number of concerns were raised about a 'cliff-edge' in co-fired ROC prices. This was cited as a reason why independent generators, in particular, had failed to sign up to long-term supply contracts with farmers (Pöyry Energy Consulting, 2006). In addition, the impending lowering of the cap raised concerns about reducing the contribution of co-firing to the abatement of CO_2 emissions from fossil fuel plant. With the Government considering electricity generation from coal likely to remain an important part of the overall generating mix, it was considered appropriate to abate carbon emissions from coal fired plant as much as possible (DTI, 2006b). A report commissioned by the UK Government (Themba Technology, 2006) found that greenhouse gas (GHG) emission reductions from co-firing can be substantial for a very wide range of biomass fuels, whether UK-based or imported, and including both biomass residues and energy crop feedstocks (DTI, 2006b).

The report also found that waste or co-product materials tend to have lower GHG emissions per unit of energy over their lifecycle than dedicated energy crops (Themba Technology, 2006), leading to calls for a removal of government subsidies for dedicated energy crops along with the minimum requirement for energy crops as part of the co-firing cap (Scottish and Southern Energy, 2006). This position has not gone unchallenged; a critique of the Themba report has argued that a number of assumptions lead to a significant underestimate of the sustainability benefits derived from energy crops, particularly SRC (Alker and Miller, 2006).

As a result of the Themba analysis, and following stakeholder consultation, the Government announced in the Energy Review Report that co-firing should be encouraged to play a long-term role in reducing the carbon emissions from fossil fuel plants (DTI, 2006b). Thus, there has been a change in emphasis from co-firing being necessary to bring on the development of energy crops, to co-firing itself being an important source of reducing carbon emissions.

A further amendment to the RO has meant that since April 2007, ROCs awarded for the co-firing of energy crops do not contribute to a supplier's 10% co-firing limit (DTI, 2007a). It was argued that this would create an additional market for energy crops and so remove the need for the minimum energy crop percentages that would have been required from 2009 onwards (Lords Hansard, 2007). However, this has been met with scepticism and disapproval from a number of representatives of suppliers of energy crop feedstocks (Country Land and Business Association, 2006; Bical, 2006).

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[4] An energy crop as currently defined by the office of gas and electricity markets (OFGEM) is a plant crop planted after 31 December 1989 grown primarily for the purpose of being a fuel or which is either miscanthus, SRC willow or SRC poplar (OFGEM, 2007). Thus annual crops such as wheat and rapeseed can be co-fired as energy crops as long as they are grown specifically for the purpose. However within the RO the focus for co-firing has been on SRC willow or miscanthus (Ilex Energy Consulting, 2003).

At present the RO is 'technology neutral', awarding ROCs for every MWh of electricity produced from any eligible renewable source. This is subject to change following a consultation where it is proposed that 'banding' be introduced from April 2009 to provide varying levels of support to different technologies. This is to encourage a greater diversity of renewable technologies and give greater support for those technologies that are currently less cost-effective. Under the amended Obligation, the cap on co-firing will be removed, 1 ROC will be awarded for every MWh from co-firing energy crops, while 2 ROCs will be awarded for every MWh from energy crops in dedicated biomass burners or in combined heat and power (CHP) (DTI, 2007a). Co-firing of regular (non-energy crop) biomass, considered an established technology, will receive a reduced level of support of 0.25 ROCs per MWh.

It is unclear whether these changes will provide sufficient stimulus for the development of a domestic supply of SRC and miscanthus. It is argued by the National Farmers' Union (NFU) of England and Wales that the minimum percentage requirement for energy crops is the most effective way to create long-term demand, and that relying on differential ROC banding provides a less secure market and thus less incentive for farmers to plant a long-term crop (NFU, 2006).

A further question is whether energy crops used for co-firing or in dedicated plant will actually be SRC willow and miscanthus, as the precise conditions required for a crop to count as an energy crop under the OFGEM definition are still subject to some uncertainty (Rosillo-Calle and Perry, 2006).

The NFU is keen that the OFGEM definition of energy crops should not restrict the use of annual crops, and they argue that it is absurd that a crop used to produce biofuel under the Renewable Transport Fuels Obligation (RTFO) could have its co-product classified as not being an energy crop under the RO if evidence was not available to demonstrate that it was always intended for energy use (NFU, 2006). Scottish Power believe the definition of energy crops should be extended to include all energy crop types such as wheat and other grains (Scottish Power, 2006).

Indeed, a DTI report suggests that while most energy crops planted are SRC and miscanthus, 'future expansion will probably occur with annual crops, which have the advantage of being much more compatible with agricultural practices and are finding considerable favour with farmers/growers' (DTI, 2007b).

As far as the RO is concerned, it does appear that despite the recent banding proposals, the development of supply chains for miscanthus and SRC willow, once a key aim within the RO, has become a lower priority.

4.2. *Climate change levy*

In addition to funding received through the RO, generators of renewable energy receive a levy exemption certificate (LEC) from the Climate Change Levy (CCL) for each MWh of renewable electricity produced. This provides an additional, albeit smaller, revenue stream of £4.3/MWh, although the amount received by the generator is subject to a supplier margin and is typically lower than this (Carbon Trust, 2006).

4.3. *European Union Emissions Trading Scheme*

The European Union Emissions Trading Scheme (EU-ETS) also provides a source of income whereby the use of biomass can count as an emissions saving for installations taking part in the scheme. The value of the carbon savings varies with the emissions cap and level of compliance, but will improve the cost-effectiveness of measures such as switching to biomass heating in industrial units or co-firing in fossil fuel plants (Rosillo-Calle and Perry, 2006).

4.4. *Renewable Transport Fuel Obligation*

The RTFO is due to commence in April 2008, and will require suppliers of transport fuels to ensure that a certain proportion is derived from renewable sources such as biofuels. The level of the RTFO will reach 5% by volume by 2010, with the obligation levels in the years 2008/09 and 2009/10 set at 2.5% and 3.75%, respectively (Department for Transport, 2007).

It is suggested that the targets will be met both by imports and a proportion of domestically grown wheat and oilseed rape (Defra, 2007a). If more efficient second generation biofuels derived from woody crops become available by 2020, as is expected by Defra (2007a), this could provide a stimulus for SRC willow and miscanthus production.

5. Current support for farmers growing dedicated energy crops

A number of grants have been available to farmers throughout the UK for the establishment of SRC willow and miscanthus with an energy end use in mind.

In England, the Energy Crops Scheme (ECS) under the 2000–2006 England Rural Development Programme (ERDP) offered £1000/ha for SRC willow and £920/ha for miscanthus. This scheme closed to applicants in the summer of 2006, but a new ECS, offering establishment grants only, will be available under the Rural Development Programme for England (RDPE) 2007–2013. This has now opened for applications although grants are not currently available as the European Commission has yet to approve the RDPE (Natural England, 2007).

In Scotland, SRC willow has been eligible for payments of £1000/ha under the Scottish Forestry Grants Scheme. Applications for this scheme closed in December 2006. The level of funding and other details of the new Scottish Forestry Grant Scheme remain dependent on the outcome of the UK's discussions with Brussels over the Rural Development Programme (SAC, 2007).

In Wales an establishment grant for SRC willow has been available to landowners through the Forestry Commission administered Woodland Grant Scheme, but at only £600/ha, the grants levels are considerably lower than those available elsewhere. This scheme closed to new applicants in 2006, and no more establishment grants are available for SRC at present (Wales Biomass Centre, 2007).

In Northern Ireland, a 3 year Challenge Fund was established for SRC willow in 2004. The average rate of assistance is £1920/ha. The Fund has now closed to new applicants, but a successor programme of support for the continued development of SRC willow is being sought (DARDNI, 2007).

In addition, since 2004 payments to landowners of up to €45/ha (depending on the uptake of the scheme across the EU) have been offered through the CAP under the Energy Crop Aid Scheme for energy crops (including conventional crops such as wheat and oilseed) that are not grown on set-aside, which have an end-user contract, and which provide a security deposit of €60/ha (RPA, 2007).

6. Focus group methodology

Against this background of farmer uncertainty, and as the first stage in a two part Theory of Planned Behaviour (TPB) study (Ajzen, 1991), this study considered the range of potential attitudes using a focus group approach. Focus groups are distinguished from other methods of group interviewing, such as 'brainstorming' or Delphi groups, by the explicit use of the group interaction to produce data and insights that would be less accessible without the interaction found in a group (Morgan, 1988). According to Morgan (1988) 'focus groups are useful when it comes to investigating *what* participants think but they excel at uncovering *why* participants think as they do'.

Focus groups have previously been used for TPB studies (Beedell and Rehman, 2000; Garforth et al., 2004), as they have the advantage of enabling data from a group of people to be gathered more quickly than through individual interviews, and they also permit the researcher to immediately follow-up participant statements in order to clarify responses.

However, there is also the risk that some participants may dominate proceedings, leading more reserved members to hold back. It must also be borne in mind that the small number of participants mean that findings cannot necessarily be generalised to wider populations. It is for this reason, as in this case, that focus groups are often used as a preliminary stage in a larger research programme that includes a more representative survey of the population (Walker, 1985).

Three groups, held in Thame (Oxfordshire), Bawtry (Nottinghamshire) and Scotlandwell (Fife), took place between November 2006 and January 2007. The locations were chosen for proximity to existing or proposed co-firing or dedicated biomass power plants. Participants were sought through a number of channels (producer groups, Farming and Wildlife Advisory Group (FWAG), National Farmers' Union of England and Wales (NFU) and SAC advisory service) with the intention being to get a broad mix of existing and potential growers of miscanthus and SRC willow.

An independent consultant facilitated the discussions, working through a series of broad open-ended questions intended to elicit information on the factors which influence the uptake of dedicated energy crops by farmers. The focus groups typically continued for between 90 and 120 min. The discussions were recorded and the output analysed by two researchers, grouping responses into the key themes reported below.

7. Findings from focus groups

Thirty-one people attended the focus groups including 28 farmers, two producer group representatives, and a power company consultant. Sixteen farmers had had experience of growing SRC willow with over half of these attending the Bawtry meeting. Several of these growers originally had contracts with the failed Arbre scheme that was to supply the Eggborough power station in 2000. But the company behind that project folded in 2002, making 40 people redundant and leaving farmers with acres of half-grown coppicing plantations on their hands.

In total only two farmers had experience of growing miscanthus, and thus the discussions were more focused on SRC willow. The area of land in energy crop production on these farms ranged from approximately 5 to 250 ha, with a median area of 15 ha. Four farmers had more than 25 ha in energy crop production, and of these two had an area greater than 100 ha.

7.1. *Motivation to grow energy crops*

There was broad consensus that the principle factor affecting a farmer's decision to grow energy crops or not was the perception of potential financial returns. In this respect the contracts available to growers under the original Arbre scheme were said to have been relatively attractive.

Another factor related to personal or ideological beliefs about climate change and fossil fuel dependency. Many of the farmers thought that growing energy crops was fundamentally a 'good' thing, whilst at the same time it was widely thought that such concerns would be a stronger driver in energy crop production in the future.

However, current uncertainty about the financial viability of energy crops appears likely to limit uptake in the short-term despite many farmers being supportive of the underlying principles. A widespread belief was that returns would improve over time, as the government is forced to increase incentives for growing energy crops as part of its programme to tackle climate change. Indeed many of the farmers growing energy crops appear to have speculated that by getting involved at an early stage they will be well placed to benefit later on.

A further factor mentioned by older farmers was the desire to maintain farm production while scaling back daily involvement. In this respect contracting out the entire energy crop production process was seen as attractive.

7.2. *Perceptions of financial returns*

The prices currently paid for energy crops are felt to be low. A key point is the comparison of returns with those from alternative crops or land uses. With wheat having risen dramatically (from £60/t in early 2006 to around £90/t in the second half of the year), the returns available look even less appealing. Within the groups there was much speculation (and some excitement) as to how high the wheat price might go. In this context it was maintained that farmers were very unlikely to sign long-term contracts for willow at the prices currently on offer. Wheat prices are higher still in 2007, with London's November wheat futures closing recently at over £140/t (Farmers Weekly, 2007).

The majority of farmers felt that it was difficult to calculate the returns from energy crops due to uncertainty over costs, potential yields and prices. In comparison farmers were very aware of returns from conventional crops and at what prices and yields they would be profitable. The lack of a mature, fully developed market with clear prices was part of the problem, with a perceived lack of transparency. At present, farmers feel they have little choice but to sell to the power stations for co-firing, where they believe they will always receive the lowest price as the power stations act as 'middle men' in the supply of energy to consumers.

The preferred situation (thought to be the most profitable) for the farmers would be to 'supply kilowatts of heat rather than kilograms of wood' to local schools and hospitals, thus capturing more value through the development of a vertically integrated business. This market is currently very underdeveloped in the UK and reliant on investment in biomass boilers and combined heat and power (CHP) plants. It is interesting to note that this market has perhaps the greatest potential in terms of cost-effective GHG savings. Nevertheless, there was acknowledgement that powers stations had a role to play in developing a market for energy crops.

7.3. *Grant support*

Very few farmers said they would consider growing energy crops without the establishment grant, due to the high upfront capital costs and uncertainties over resulting net income. Indeed it was thought that net income would almost certainly be negative at current market prices without grant support. New applications to the English Energy Crop Scheme have been suspended since July 2006 with farmers uncertain as to when these grants will reappear, and expecting grant levels to be lower than previously available. It was felt these issues send poor signals to potential growers, particularly as establishment costs are unlikely to fall significantly in the near future.

The payments of up to €45/ha (on non-set-aside) under the EU Energy Crop Aid Scheme did not seem to be an important factor in encouraging uptake, as payments are low in comparison to establishment costs. In principle, however, the additional financial support was welcome. Anecdotal evidence suggests that the administrative requirements for claiming the Energy Crop Aid can be frustrating for farmers due to interaction of claims made under the Single Payment Scheme and the requirement for the processor to lodge a €60/ha deposit.

An important aspect of energy crop production is that producers have high establishment costs yet no income until the first harvest after 4 years. One suggestion made at the discussion groups was that grant monies could be targeted at this period to resolve cash flow problems which may otherwise limit crop uptake.

7.4. Contracts with power stations

There was recognition that with the nature of the cropping cycle, farmers and end-users would continue to rely on contracts, particularly with limited alternative markets for dedicated energy crops (SRC in particular, as miscanthus has alternative uses, e.g. for animal bedding). However, farmers were sceptical that prices offered by power stations would be sufficient to encourage significant uptake. Many believed energy crop prices were calculated when wheat was at £60 per tonne and had failed to rise sufficiently since then. Some felt contracts allowed for lower prices to be paid than they had been led to believe. There was also concern about a farmer's ability to enforce contracts if the end-user decided they did not want the crop or would only pay a lower price. Nevertheless, there was widespread acceptance that co-firing offers a lifeline to energy crop growers and in many cases constitutes the only viable market.

There was a belief that power stations were motivated primarily by renewable energy obligations and did not really want to use SRC to meet these, as it was more expensive than alternative co-firing feedstocks from forestry or imports. It was also felt that power stations were wavering in their commitment to SRC due to potential changes in the RO rules relating to co-firing. This would seem to tally with the expressed opinions of a number of generators who would rather have freedom to co-fire whatever feedstock they choose (Scottish and Southern Energy, 2006; Scottish Power, 2006), and suggests that removing the cap on energy crops could result in demand from co-firers declining significantly.

7.5. Markets

The 'chicken-and-egg' problem facing market development was identified as an important issue. Farmers have few incentives to grow energy crops without the existence of competitive markets, and potential users have little incentive to invest in the technologies necessary to develop these markets if supply is both limited and uncertain. Many farmers felt that the government must play a significant role to stimulate demand through, for example, providing grants to local authorities, hospitals, schools and businesses to install biomass boilers. Equally it was felt that once a 'critical mass' of energy crop growers had been established, this would increase confidence in energy crop supply, thus prompting more widespread development of markets. Growers perceive that without intervention to stimulate this market then it may take a long time for this 'critical mass' to be achieved.

There was also broad recognition that producer groups and co-operatives could play a key role in establishing new markets, as end-users are unlikely to deal with individual growers. Local markets for heat and for CHP were thought to have the most potential to be profitable by allowing farmers to deal directly (through co-operatives or producer groups) with the end-users.

Farmers were keen to stress that development of a mature market for energy crops, would be preferable to a culture of 'handouts'. However, it was conceded that, unless or until, higher energy prices make production more competitive than alternative land uses, subsidies (direct or indirect) would be required for energy crop production to become more widespread. Farmers pointed to Sweden, Germany and Austria as places where markets appear to have developed successfully, and felt that policy makers could learn lessons from the experience gained in these countries.

7.6. Producer groups and co-operation

Co-operation between farmers was seen as essential if new and more profitable markets are to be developed. It was noted that, historically, crop production has not resulted in significant levels of co-operation between farmers. Areas where co-operation should bring benefits include the sharing of experiences on establishment, management, harvesting, processing and marketing of the crops, and collective purchasing of required machinery.

The importance of producer groups was acknowledged, but with awareness that they may not be the most impartial sources of information on energy crop production. The main concerns related to information on potential costs and returns and the more problematic aspects of production. In practice, however, producer groups appeared to enjoy good relationships with most producers and as a result this was not a major issue.

7.7. Type of land used to grow energy crops

Energy crops are more likely to be grown on a farm's least productive land, including arable land, set-aside and permanent pasture taken out of dairy production or currently in grass lets. This reflects the speculative nature of much energy crop production. Several more experienced growers stressed the direct relationship between yields and land productivity, although crop management was also important. Some arable farmers expressed interest in growing energy crop on permanent set-aside land to generate additional income. However, this land tends to be the least productive of a farm's arable land with low yield expectations. Recent European Commission proposals mean set-aside is likely to be suspended in the UK in 2008, with much speculation that it will be scrapped, at least in its current form. These developments will clearly have an effect on the potential for future uptake of energy crops on set-aside.

For most growers, energy crops are a diversification rather than a primary farm enterprise. A small number of farmers had put most or all of their land into energy crop production, which had enabled them to retire or focus on other activities such as contracting. At the moment farmers appear reluctant to use their most productive land for energy crops, but it was stressed that this was linked to the perception of their poor profitability. In principle, many farmers may be willing to consider growing energy crops on more productive land, providing that agronomic conditions are suitable and they have confidence that energy crop production will be competitive in the long term. Essentially if returns from energy crop production were to be equal to or better than alternative uses, there appears no reason why uptake of energy crop production on all suitable types of land would not increase. However this seems unlikely in the short term, and one can speculate about the longer term opportunity costs of energy crop land uses, given rapidly increasing food demand from China and India.

The perceived negative impact of SRC roots on field drainage can be an important factor in the decision whether or not to grow energy crops. It was interesting that these concerns tended to come from potential growers rather than experienced ones; the latter group suggesting that careful site selection could prevent this from becoming a serious issue. Furthermore, it is unclear to what extent SRC damages field drainage above and beyond natural deterioration. Nonetheless, at least one producer group advises growers not to grow SRC where there are shallow drains (Thames Valley Bioenergy Coppice, 2007).

The uncertain cost of returning land to alternative production was also a concern expressed by a number of farmers. Some existing growers suggested that it would not be too expensive or difficult; although no one had direct experience.

7.8. *Farm business impacts*

Most farmers said they would need to hire contractors for SRC establishment and harvesting due to the expense of purchasing specialist equipment. For miscanthus it was felt that existing farm equipment might be suitable. Some already make extensive use of contractors in other aspects of their businesses, and therefore using energy crop contractors would have little impact on the farm structure. However, for those farmers who have not traditionally made use of contractors this may be an issue. It was also suggested that growing energy crops could provide an opportunity to reduce fixed costs associated with machinery and labour, thus allowing farmers to engage in other on- or off-farm activities. Some growers have restructured to such an extent that they have become the providers of energy crop contracting services to other growers.

7.9. *UK farming sector impacts*

There was unanimous agreement that the development of energy crops could only be good for the UK farming sector, as long as farmers could make a profit from growing them. It was thought that the impact of taking land out of production from other agricultural commodities would have the effect of pushing up prices in general and thus benefiting UK agriculture. Several farmers reported that their neighbours had expressed interest in growing energy crops if financial viability could be demonstrated.

7.10. *Environmental impacts*

Several farmers with experience of growing energy crops felt that SRC offered clear biodiversity benefits, but that these were not widely recognised by environmental groups and government bodies. Farmers were receiving mixed messages both from different organisations and on occasions from different individuals within a single organisation. Most farmers felt further research would be useful to clarify the impact of energy crops on biodiversity so that a more consistent message can be given.

A number of farmers believed that the public were supportive of them growing energy crops, seeing it as a positive way of tackling climate change. Public concerns over the landscape and visual impacts of energy crops were not thought to be significant at present, but opposition may occur if large-scale planting were to take place. Several farmers were keen to point out as an example that initial public reaction to oilseed rape had been negative but that public perceptions were no longer hostile.

The potential for willow to provide environmental services such as water purification on floodplains through the uptake of excess nutrients such as nitrogen was identified. Use of sewage sludge on energy crops was cited as having the twin benefits of providing a safe disposal of waste outside the food chain and acting as a source of nutrients for the crop.

7.11. *Sources of information and information gaps*

A leaflet on short rotation coppice available from Defra (2006b) had been useful in general terms, although several farmers complained that staff at Defra and the Rural Payments Agency had not been able to provide any further information. For many farmers, producer groups had been the main information source. Farmers also received information from power companies and agronomist services contracted to these companies. However, none of these sources were considered to be comprehensive.

Established growers said much of their knowledge was from personal experience and sharing information with other farmers through producer groups and co-operatives. Site visits and talking to growers were also mentioned as a good way for farmers to find out about the practicalities of energy crop production. It was stressed that there was a need for information that was clearly independent, objective and practical.

None of the farmers had obtained information from the NFU, traditional agronomists, farm advisors or the Biomass Energy Centre; recently set up by the Forestry Commission in response to the findings of the Biomass Task Force. It was reported that the Biomass Energy Centre had actually approached a number of the growers and producer groups from the Bawtry Focus Group in order to obtain information about energy crops.

Several farmers noted a lack of UK (or indeed Scotland)-specific information on growing energy crops, and where information could be found it was not comprehensive and quite fragmented. One farmer suggested that a simple crib sheet with step-by-step details of each stage in the production cycle (establishment, management and harvesting of the crop), as well as details of all administrative requirements, would be helpful. A key gap was also identified in relation to marketing and end uses of energy crops, including information on installing biomass boilers both for on-farm and local energy uses.

It was thought that clear, practical information from impartial research organisations, disseminated through the Biomass Energy Centre, had the potential to complement information provided by producer groups.

8. Conclusion

While participants express optimism about the future of energy crop production, there are clearly several barriers to widespread adoption. Key among these is financial returns, and the fact that competing activities are much more rewarding—in particular, wheat and oilseed rape, with current high prices partly driven by demand for liquid biofuels. This raises an important policy issue relating to the cost of abating carbon emissions. Using perennial energy crops for heating is typically a very cost-effective use of biomass to reduce carbon emissions, whereas transport biofuels from grain or oilseed is a much more expensive approach (Carbon Trust, 2005; SAC, 2005).

While the forthcoming RTFO will provide a continued incentive to grow wheat and oilseed rape for biofuels, there is no such support mechanism for renewable heat. The focus on renewable electricity, and more latterly transport fuels, to the exclusion of renewable heat is a concern to both the Royal Commission on Environmental Pollution and the Biomass Task

Force (RCEP, 2004; Biomass Task Force, 2005). While the RCEP proposed a 'Renewable Heat Obligation', the Biomass Task Force considered this unworkable, favouring instead a grant programme for boilers, subsequently adopted by Defra as Round 3 of the Bio-energy Capital Grants Scheme (Defra, 2007b). As indicated, farmers believe such grants crucial to create a local demand for renewable heat, which they see as the most profitable future outlet for energy crops.

While successful development of local markets should go some way to increasing returns to farmers and providing reassurance that someone will be able to take the crop at a competitive price, at the current time, planting grants and contracts are still required. There is a need to increase farmer confidence in the contracts, be it perhaps through government underwriting or some form of insurance. An early decision on the establishment grant would also be welcome by farmers as it would mean one less uncertainty.

Finally, farmers need trusted information to make decisions, which predominantly come down to financial considerations at an individual farm level. The issue of SRC roots potentially damaging field drains is a good example where the farmer needs to know how likely this is to happen in his case, and if so, how much it would cost to rectify. It seems that the Biomass Energy Centre, although currently still building up knowledge, is in a good position to become the leading authority.

In terms of further research, there is a need to identify energy crop adoption intentions from a much larger range of farmers. Following from the focus groups, a postal survey based on the Theory of Planned Behaviour (Ajzen, 1991) will be issued to establish the likely wider extent of adoption, as well as identifying the relative importance of drivers and barriers highlighted by the groups. This will enable a better understanding of how policy makers could tackle the specific issues that limit the potential of dedicated energy crops in the UK.

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References

ADAS, 2003. The mid-term evaluation of the England Rural Development Programme (ERDP): energy crop scheme. Available at ⟨http://www.defra.gov.uk/erdp/pdfs/midterm/cs_ecs_3.pdf⟩ (accessed August 2007).
Ajzen, I., 1991. The theory of planned behaviour. Organizational Behaviour and Human Decision Processes 50, 179–211.
Ajzen, I., Fishbein, M., 1980. Attitudes, Personality and Behaviour. Open University Press, Milton Keynes.
Alker, G.R., Miller, M., 2006. Critique of 'Evaluating the Sustainability of Co-firing in the UK' a recent report published by the Department of Trade and Industry. Available at ⟨http://www.berr.gov.uk/files/file36247.pdf⟩ (accessed August 2007).
Andersen, R.S., Towers, W., Smith, P., 2005. Assessing the potential for biomass energy to contribute to Scotland's renewable energy needs. Biomass & Bioenergy 29, 73–82.
Beedell, J., Rehman, T., 2000. Using social-psychology models to understand farmers' conservation behaviour. Journal of Rural Studies 16, 117–127.
Bical, 2006. Biomass Industrial Crops Ltd. (Bical) response to statutory consultation on the Renewables Obligation Order 2007. Available at ⟨http://www.berr.gov.uk/files/file36708.pdf⟩ (accessed August 2007).
Biomass Task Force, 2005. Report to Government, October 2005. Available at ⟨http://www.defra.gov.uk/farm/crops/industrial/energy/biomass-taskforce/pdf/btf-finalreport.pdf⟩ (accessed August 2007).
Campbell Carr, 2003. Analysis of the effect of co-firing biomass with fossil fuels on the Renewables Obligation: A report prepared for the British Wind Energy Association and Friends of the Earth, November 2003. Available at ⟨http://www.foe.co.uk/resource/reports/cofiring_renewables_obligation.pdf⟩ (accessed August 2007).
Carbon Trust, 2005. Biomass sector review for the Carbon Trust, October 2005. Available at ⟨http://www.carbontrust.co.uk/publications/publicationdetail?productid=CTC512⟩ (accessed July 2007).
Carbon Trust, 2006. Policy frameworks for renewables: analysis on policy frameworks to drive future investment in near and long-term renewable power in the UK. Available at ⟨http://www.carbontrust.co.uk/Publications/publicationdetail.htm?productid=CTC610⟩ (accessed August 2007).
Charles, M.B., Ryan, R., Ryan, N., Oloruntoba, R., 2007. Public policy and biofuels: the way forward? Energy Policy 35, 5737–5746.
Council of the European Union, 2007. Presidency Conclusions, Brussels European Council, 8/9 March 2007. Available at ⟨http://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/ec/93135.pdf⟩ (accessed July 2007).
Country Land and Business Association, 2006. Draft response to statutory consultation on the Renewables Obligation Order 2007. Available at ⟨http://www.berr.gov.uk/files/file36715.pdf⟩ (accessed August 2007).
DARDNI, 2007. Renewable Energy Action Plan. Department of Agriculture and Rural Development, Northern Ireland, January 2007. Available at ⟨http://www.dardni.gov.uk/renewable-energy-action-plan-2.pdf⟩ (accessed July 2007).
Defra, 2006a. Creating value from renewable materials: a strategy for non-food crops and uses—two year progress report, Department for Environment, Food and Rural Affairs, November 2006. Available at ⟨http://www.defra.gov.uk/farm/crops/industrial/pdf/nfc-progress-0611.pdf⟩ (accessed July 2007).
Defra, 2006b. Best practice guidelines for applicants to Defra's energy crops scheme: growing short rotation coppice. Available at ⟨http://www.defra.gov.uk/erdp/pdfs/schemes/energy/short-rotation-coppice.pdf⟩ (accessed October 2006).
Defra, 2007a. UK Biomass Strategy. Department for Environment, Food and Rural Affairs May 2007.
Defra, 2007b. Bio-energy capital grants scheme, Defra website. Available at ⟨http://www.defra.gov.uk/farm/crops/industrial/energy/capital-grants.htm⟩ (accessed August 2007).
Department for Transport, 2007. Consultation on the Draft Renewable Transport Fuel Obligations Order 2007, February 2007. Available at ⟨http://www.dft.gov.uk/consultations/closed/draftrtfo/rtfo⟩ (accessed July 2007).
DTI, 2003a. The Renewables Obligation (Amendment) Order 2003 Statutory Consultation. Department of Trade and Industry Available at ⟨http://www.berr.gov.uk/files/file22098.pdf⟩ (accessed August 2007).
DTI, 2003b. Renewables innovation review, Department of Trade and Industry. Available at ⟨http://www.dti.gov.uk/files/file22017.pdf⟩ (accessed July 2007).
DTI, 2006a. Terms of reference for a review of co-firing, Department of Trade and Industry, March 2006. Available at ⟨http://www.berr.gov.uk/files/file27963.pdf⟩ (accessed August 2007).
DTI, 2006b. Renewable energy: reform of the renewables obligation and statutory consultation on the Renewables Obligation Order 2007—an energy review consultation. Department for Trade and Industry, October 2006. Available at ⟨http://www.berr.gov.uk/files/file34470.pdf⟩ (accessed August 2007).
DTI, 2007a. Renewable energy: reform of the Renewables Obligation. Department for Trade and Industry, May 2007. Available at ⟨http://www.berr.gov.uk/files/file39497.pdf⟩ (accessed July 2007).
DTI, 2007b. Impact of banding the Renewables Obligation—costs of electricity production. Report by Ernst & Young to the Department for Trade and Industry, April 2007. Available at ⟨http://www.berr.gov.uk/files/file39038.pdf⟩ (accessed August 2007).
Ericsson, K., Nilsson, L., 2006. Assessment of the potential biomass supply in Europe using a resource-focused approach. Biomass & Bioenergy 30, 1–15.
European Commission, 2007. Cereals: council approves zero set-aside rate for autumn 2007 and spring 2008 sowings. Available at ⟨http://europa.eu/rapid/pressReleasesAction.do?reference=IP/07/1402⟩ (accessed September 2007).
FAO, 2007. Crop prospects and food situation, No. 5, October 2007. Food and Agriculture Organisation of the United Nations, Rome. Available at ftp://ftp.fao.org/docrep/fao/010/ah873e/ah873e00.pdf (accessed November 2007).
Farmers Weekly, 2007. Farmers Weekly, 10 August 2007.
Foxon, T.J., Gross, R., Chase, A., Howes, J., Arnall, A., Anderson, D., 2005. UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures. Energy Policy 33 (16), 2123–2137.
Garforth, C., Rehman, T., McKemey, K., Tranter, R.B., Cooke, R.J., Yates, C.M., Park, J.R., Doward, P.T., 2004. Improving the design of knowledge transfer strategies by understanding farmer attitudes and behaviour. Journal of Farm Management 12, 17–32.
Ilex Energy Consulting, 2003. An assessment of changes to the Renewables Obligation rules relating to co-firing: a report to DTI, August 2003. Available at ⟨http://www.berr.gov.uk/files/file21086.pdf⟩ (accessed August 2007).
IPA Consulting, 2006. The economics of co-firing. Report to Department of Trade and Industry, July 2006. Available at ⟨http://www.berr.gov.uk/files/file34449.pdf⟩ (accessed August 2007).
Jacobsson, S., Bergek, A., 2004. Transforming the energy sector: the evolution of technological systems in renewable energy technology. Industrial and Corporate Change 13 (5), 815–849.
Kemp, R., Schot, J., Hoogma, R., 1998. Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. Technology Analysis and Strategic Management 10 (2), 175–195.

Lords Hansard, 2007. 15 March 2007: Column GC59. Available at 〈http://www.publications.parliament.uk/pa/ld200607/ldhansrd/text/70315-gc0002.htm〉 (accessed August 2007).

Mattison, E.H.A., Norris, K., 2007. Intentions of UK farmers toward biofuel crop production: implications for policy targets and land use change. Environmental Science and Technology 41 (16), 5589–5594.

Meijer, I.S.M., Hekkert, M.P., Koppenjan, J.F.M., 2007. The influence of perceived uncertainty on entrepreneurial action in emerging renewable energy technology; biomass gasification projects in the Netherlands. Energy Policy 35, 5836–5854.

Morgan, L.D., 1988. Focus Groups as Qualitative Research. Sage Publications, Newbury Park.

Natural England, 2007. Energy Crops Scheme page on Natural England website. Available at 〈http://www.naturalengland.org.uk/planning/grants-funding/energy-crops/default.htm〉 (accessed October 2007).

NFPA, 2007. ROC auction prices page on Non-fossil Purchasing Agency website 〈http://www.nfpa.co.uk〉 (accessed August 2007).

NFU, 2006. Statutory consultation on the Renewables Obligation Order 2007—Response from the National Farmers' Union of England and Wales. Available at 〈http://www.berr.gov.uk/files/file36752.pdf〉 (accessed August 2007).

OFGEM, 2007. Renewables Obligation: fuel measurement and sampling guidance, March 2007.

Pöyry Energy Consulting, 2006. Creating ski slopes from cliff edges: removing volume risk from the Renewables Obligation, May 2006. Available at 〈http://www.ilexenergy.com/pages/157SkiSlopesFromCliffEdges_v3_0.doc〉 (accessed August 2007).

Raven, R.P.J.M., 2005. Strategic niche management for biomass. Thesis, Eindhoven University of Technology, Eindhoven.

RCEP, 2000. Energy—the changing climate: the 22nd Report by the Royal Commission on Environmental Pollution, London.

RCEP, 2004. Biomass as a renewable energy source: a limited report by the Royal Commission on Environmental Pollution, London.

Rosenqvist, H., Dawson, M., 2005. Economics of willow growing in Northern Ireland. Biomass and Bioenergy 28, 7–14.

Rosillo-Calle, F., Perry, M., 2006. International Energy Agency (IEA) Bioenergy Task 40—Sustainable International BioEnergy Trade: securing supply and demand. Country Report for United Kingdom. Imperial College of Science, Technology and Medicine, London.

RPA, 2007. Energy Aid Payments Scheme, Rural Payments Agency website. Available at 〈http://www.rpa.gov.uk〉 (accessed August 2007).

SAC, 2005. Farm level economic impacts of energy crop production: Final report to Defra, August 2005. Available at: 〈http://www.defra.gov.uk/science/Project_Data/DocumentLibrary/NF0431/NF0431_4015_FRA.doc〉 (accessed July 2007).

SAC, 2007. Commercial viability of alternative non-food crops and biomass on Scottish Farms—a special study supported under SEERAD Advisory Activity 211, March 2007. Available at 〈http://www.sac.ac.uk/mainrep/pdfs/nonfood biomass.pdf〉 (accessed July 2007).

Sagar, A.D., van der Zwaan, B., 2006. Technological innovation in the energy sector: R&D, deployment, and learning-by-doing. Energy Policy 34, 2601–2608.

Scottish and Southern Energy, 2006. Response to Statutory Consultation on the Renewables Obligation Order 2007. Available at 〈http://www.berr.gov.uk/files/file36743.pdf〉 (accessed August 2007).

Scottish Power, 2006. Response to the Statutory Consultation on the Renewables Obligation Order 2007. Available at 〈http://www.berr.gov.uk/files/file36745.pdf〉 accessed August 2007.

Skytte, K., Meibom, P., Capral Henriksen, T., 2006. Electricity from biomass in the European Union—with or without biomass import? Biomass and Bioenergy 30, 385–392.

Strawson, J., 2005. Energy Crops and the Market for Biomass in the UK. Nuffield Farming Scholarships Trust January 2005.

Styles, D., Jones, M.B., 2007. Current and future financial competitiveness of electricity and heat from energy crops: a case study from Ireland. Energy Policy 35, 4355–4367.

Thames Valley Bioenergy Coppice, 2007. Green energy from your land: a fair deal from energy crops in the Thames Valley. Available at 〈http://www.tvbioenergy-coppice.co.uk/pdf/a-fair-deal.pdf〉 (accessed August 2007).

Themba Technology, 2006. Evaluating the sustainability of co-firing in the UK (Report for the DTI). Themba Technology Ltd. in collaboration with The Edinburgh Centre for Carbon Management September 2006.

Unruh, G.C., 2000. Understanding carbon lock-in. Energy Policy (30), 317–325.

Upham, P., Speakman, D., 2007. Stakeholder opinion on constrained 2030 bioenergy scenarios for North West England. Energy Policy 35, 5549–5561.

Van der Laak, W.W.M., Raven, R.P.J.M., Verbong, G.P.J., 2007. Strategic niche management for biofuels: analysing past experiments for developing new biofuel policies. Energy Policy 35, 3213–3225.

Wales Biomass Centre, 2007. Costs, markets and grants for energy crops, Wales Biomass Centre website. Available at 〈http://www.walesbiomass.org/bio-economics.htm〉 (accessed August 2007).

Walker, R.L., 1985. Applied Qualitative Research. Gower, VT.

Welsh Assembly Government, 2007. Personal communication from Vicky Davies, Rural Development Adviser, Technical Services Division, Welsh Assembly Government, Llandrindod Wells.

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FARMER ATTITUDES AND INTENTIONS TOWARDS THE ADOPTION OF PERENNIAL ENERGY CROPS IN THE UK: AN APPLICATION OF THE THEORY OF PLANNED BEHAVIOUR

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ABSTRACT: The UK Biomass Strategy suggests that to reach the technical potential of perennial energy crops such as short rotation coppice (SRC) willow and miscanthus by 2020 would require 350,000 hectares of land. This would represent a more than 20-fold increase on the current area of 15,546 hectares. The decisions of individual farmers whether or not to grow these crops are therefore a key potential constraint on supply. A postal survey using the social psychology technique the Theory of Planned Behaviour was used to assess behavioural intentions, attitudes, subjective norms, and perceived behavioural control towards the adoption of perennial energy crops. Results suggest that uptake will be minimal unless a number of barriers to adoption are overcome. These include the perceived lack of security and stability of income from contracts, disruption to cashflow, and reduction in the flexibility of the farm business.

Keywords: agriculture, barriers to bioenergy, energy crops

1 INTRODUCTION

The twin concerns of climate change and energy security have increased attention on renewable energy. In the UK, these factors have combined with an agricultural reform process that has highlighted the need for farmers to diversify away from traditionally supported arable and livestock products. Accordingly, the UK Government has in recent years demonstrated an increasing enthusiasm for the use of biomass as a source of electricity, heat and transport fuel. The UK Biomass Strategy [1] states the Government's intention to bring about a major expansion in both the supply and use of biomass in the UK, indicating that biomass will have a central role to play in meeting the EU target of 20% of renewable energy by 2020 [1].

While the UK Biomass Strategy proposes an increase in the use of biomass for heat, electricity and biofuels, beyond acknowledging the 10% minimum share of biofuels target for 2020 [2] it does not include specific targets for particular feedstocks or end uses. It does, however, outline what the UK Government considers to be the potential UK supply of biomass feedstocks up to 2020. These feedstocks include forestry, wood waste, conventional agricultural crops such as wheat and oilseed rape, straw, perennial energy crops such as short rotation coppice (SRC) willow and miscanthus, and agricultural waste [3, 1].

To increase available biomass, Defra [1] favours obtaining an additional 1 million dry tonnes of wood per annum from woodland and wood waste, more use of manures and slurries, and a substantial growth in uptake of perennial energy crops. Of these sources, it is the anticipated change in levels of perennial energy crops that is most dramatic. The technical potential of energy crops is estimated to be 17.2 TWh (1.48 Mtoe), while current availability is 0.07 - 0.09 Mtoe [1]. Such an increase would represent an almost 20-fold increase in the level of supply, albeit from a low level.

To reach the technical potential of perennial energy crops by 2020 [1] would require 350,000 hectares (ha) of land, which is roughly 6.5% of UK arable and set-aside land, assuming an average annual yield of 9 odt/ha [1]. The Renewables Innovation Review [4] suggests this is a realistic area once a number of constraints, including competition from other markets are taken into account.

The key feature of this, and other estimates of future perennial energy crops supply [3, 5] is the assumption about farmer behaviour. It is taken for granted that farmers will choose to grow perennial energy crops up to the level of the constraints that they identify. However, this assumption does not seem to be supported by experience to date.

Defra's Energy Crops Scheme, which provides establishment grants for SRC willow and miscanthus, along with support for developing SRC producer groups, had a number of objectives for the first period of the England Rural Development Programme (ERDP) (2000-2006). These included the planting, by 2006, of 16,700 ha of SRC and 5000 ha of miscanthus in England [6]. When the scheme closed to applications, in July 2006, only 1180 ha of SRC and 3356 ha of miscanthus had been planted [7], representing 20% of the target level. This does, however, mark an improvement over the uptake by the half-way point in 2003, where only 2% of the SRC target and 3% of the miscanthus target had been planted [6].

More recently there has been an increase in interest in the payments, with applications for planting in 2007 due to take the area of miscanthus to 12,627 ha, and SRC to 2600 ha in England [7].

In Scotland the area planted or approved for planting up until the end of 2006 is 300 ha. Current applications for planting in 2007 and 2008 amount to around 600 ha [8]. In Northern Ireland, 400 ha of SRC have been planted or approved for planting to date, and a further 410 ha have been approved for the 2007 planting year [9], while in Wales there is currently 40ha of SRC and 72 ha of miscanthus [10]. The current total area of energy crops in the UK is 15,546 ha for SRC willow and miscanthus combined [1].

This paper adds to a growing literature on perennial energy crops and the development of biomass energy in the UK, Europe and beyond [11, 12, 13]. While there has been much focus on techno-economic aspects and theoretical supply chain potential [14, 15, 16], broad stakeholder opinion [17] and wider public policy implications [13], relatively little is known about how individual farmers will respond to the opportunities presented by these relatively novel crops. Strawson [18], writing from the perspective of a farmer with land already committed to SRC willow, and at a time when returns from alternative activities were much lower than at present, offers a relatively upbeat assessment of the potential attractiveness of the crop. However, in the context of a significant and ongoing global rise in the price of agricultural commodities such as wheat [19], a changing agricultural policy landscape in the EU [20], and a UK renewable energy support mechanism that is under review [21], it is important to gain an up-to-date understanding of farmers' attitudes and behavioural intentions towards the adoption of perennial energy crops.

This paper will show that for perennial energy crop feedstocks such as SRC willow and miscanthus, the likely level of supply will be considerably below the theoretical potential unless a number of barriers to their adoption by farmers are overcome. The paper is structured as follows. The next section outlines the framework for investigating the behavioural intentions of UK farmers towards the adoption of perennial energy crops, followed by a description of the survey technique. The results are then presented, with the subsequent discussion looking at the implications of the findings for policy makers.

2 THEORETICAL APPROACH

The Theory of Reasoned Action (TORA) [22] and its extension the Theory of Planned Behaviour (TPB) [23] provide the conceptual framework for investigating the attitudes and intentions of farmers towards the adoption of perennial energy crops. Both the TORA and the TPB have been widely used in agricultural research to understand barriers and drivers to the adoption of new technologies and practices [24, 25, 26] and to estimate the likely scale of adoption of particular activities [27].

According to the TORA, the intention to adopt a particular behaviour is a function of attitudes towards the behaviour and the subjective norm, that is the extent to which one is influenced by the views of other people regarding the behaviour [22].

Attitudes are a product of the extent to which one expects the behaviour to result in specific outcomes (outcome beliefs) and the importance of those outcomes (outcome evaluations). The subjective norm is a function of the perceived support of salient referents (people to whom respondents might turn for advice) towards the behaviour (subjective beliefs) and the motivation to comply with those beliefs. The TORA claims that the intention to perform a particular behaviour is a reliable indicator of actual future behaviour if the expressed attitude towards this behaviour and/or the perceived social pressure to do so correlate closely with the stated intent. A comparison of the strength of correlation of the attitude and subjective norm with the stated intent towards the adoption of SRC willow or miscanthus indicates which of the two components has greater influence on the farmers' decision relating to the adoption of these crops [22].

Theoretical developments in social psychology led to the Theory of Planned Behaviour (see Figure 1), an extension of the TORA that incorporates 'perceived behavioural control' as a measure of the extent to which people believe they are able to control the outcome [23]. This followed studies suggesting that TORA performed poorly where the perceived efficacy of achieving the expected result was low - in which case the behaviour would not be attempted regardless of the strength of the attitudinal and social influences [28].

Perceived behavioural control is an individual's assessment of their own ability (control belief) to perform a particular behaviour and their capability (power of control). The TPB states that perceived behavioural control can also predict behavioural intent. The contribution of perceived behavioural control is assessed by comparing the strength of its correlation with intent with that of the other two causal components [23].

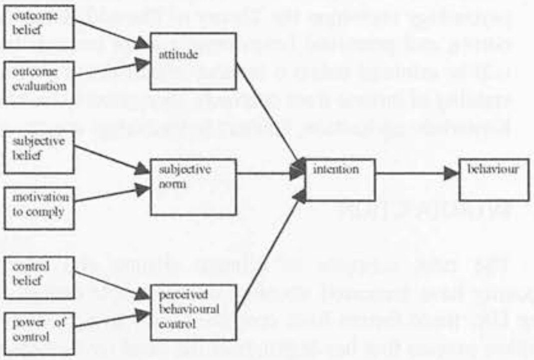

Figure 1: Theory of Planned Behaviour

Of central importance within a TPB study is the principle of compatibility, that is "relations between attitudes and behaviours are maximally strong to the extent that their action, target, context, and time elements are assessed at the same level of generality or specificity" [29]. In this study the TPB is applied to predicting farmers' behaviour towards the adoption of perennial energy crops over the next five years.

3 THEORY OF PLANNED BEHAVIOUR STUDY

The research comprised of a two stage interdependent data gathering process. Initially sets of outcome beliefs and salient referents were identified through focus group discussions with farmers in three different areas of the UK [30]. These took place in Thame (Oxfordshire), Bawtry (Nottinghamshire), and Scotlandwell (Fife), between November 2006 and January 2007. The locations were chosen for proximity to existing or proposed co-firing or dedicated biomass power plants, and attracted a mix both of farmers who had experience of growing perennial energy crops and those with no such experience.

The second stage involved using the identified outcome beliefs and salient referents in a structured questionnaire. Following a pilot survey, questionnaires were sent to 1500 farmers in three areas where SRC willow and miscanthus had already been planted under Defra's Energy Crops Scheme in England, and that were within 25 miles of either a co-firing or dedicated biomass power plant. It was decided that this would be preferable to a survey covering the whole of the UK, as in some areas there has been no development of perennial energy crops, co-firing or dedicated biomass power plant. By focusing on areas where there is an existing source of demand, it was considered that the questionnaires would be of more relevance to farmers. Within these areas, farmers were selected at random from a business directory. In all, 150 usable responses were received - a response rate of 10%.

Farmers were asked to score a response to the questions on a 5 point scale. These responses were numerically coded from -2 to +2 for analysis. Table I shows the question structure for each construct.

Table I: Question structure for the TPB survey

TPB Construct	Question Structure	Measurement scale
Behavioural intention	Are you intending to plant SRC willow on your farm in the next 5 years?	Certainly not, probably not, unsure, probably, certainly
Stated attitude	Choosing to plant SRC willow on my farm in the next 5 years would be a good decision	Strongly disagree, disagree, unsure, agree, strongly agree
Stated subjective norm	People whose opinions I value think I should plant SRC willow on my farm in the next 5 years	Strongly disagree, disagree, unsure, agree, strongly agree
Outcome evaluation	Do you agree or disagree with the following statements?	Strongly disagree, disagree, unsure, agree, strongly agree
Belief strength	How important are the following to you?	Unimportant, not very important, no opinion, important, very important
Subjective belief	Do you think the following would approve or disapprove of you growing SRC willow on your farm in the next 5 years?	Strongly disapprove, disapprove, unsure, approve, strongly approve
Motivation to comply	Would you follow the advice of the groups below in deciding whether or not to grow SRC willow on your farm in the next 5 years?	Very unlikely, unlikely, unsure, likely, highly likely
Perceived difficulty	How difficult would it be to grow SRC willow on your farm in the next 5 years?	Very difficult, difficult, unsure, easy, very easy
Perceived ability	How confident are you of being able to grow SRC willow on your farm in the next 5 years?	Not at all confident, not very confident, don't know, confident, very confident

Farmers were also invited to add their own thoughts in a comments box at the end of the questionnaire.

4 RESULTS

4.1 Description of the sample

The description of the sample is divided into three sub-sections, broadly following the format employed by the University of Reading in a TPB study for Defra in 2006 [26]. The sub-sections are farm characteristics, farm operations and farmer traits (Tables II to IV).

About 40% of the sample were mixed arable and livestock, followed by specialist dairy (25%), with beef and/or sheep and general cropping (arable) both at 12%. Specialist cereals accounted for just over 4%, and pigs and/or poultry just over 3%. Others (nearly 3%) comprised of a mixture of the main categories along with specialist vegetables. Of the five farmland types, all lowland dominated, with over 80% of the sample falling into this category, followed by mostly lowland (8%) and half and half (just under 5%). Just over 3% were all upland, with less than 1% mostly upland. The mean farmed area for the whole sample was 188ha, whereas the median area was 112ha.

Table II: Sample description based on farm characterstics

Farm parameters	Overall sample (n=150)		
	Number of respondents	Percentage (%)	Mean, sem and median values
Farm types	**146**	-	-
Specialist dairy	36	24.7	
Beef and/or sheep	18	12.3	
Pigs and/or poultry	5	3.4	
Mixed arable and livestock	59	40.4	
Specialist cereals	6	4.1	
General cropping (arable)	18	12.3	
Other	4	2.7	
Farmland type	**149**	-	-
All lowland	124	83.2	
Mostly lowland	12	8.1	
Half and half	7	4.7	
Mostly upland	1	0.7	
All upland	5	3.4	
Total farmed area (ha)	**127**		188.3 + 21.73; 112ha
Up to 58ha	32	25.2	
58.1 - 112ha	32	25.2	
112.1 - 230ha	33	26.0	
>230ha	30	23.6	
Tenure	**103**		
Tenanted	20	19.4	
Owned outright	49	47.6	
Part tenanted/part owned	34	33.0	

Table III describes the sample based on farm operations. Just over half recorded annual sales of agricultural produce of over £100,000. About a fifth had sales of £50 - 100,000, and a similar proportion had sales of £10 - 50,000. Fewer than 10% of respondents had annual sales of less than £10,000. In terms of the proportional contribution of farming to annual household income, over half indicated that they are fully dependent, with one fifth about 75% dependent on farming. 61% of respondents indicated that their farm has made a moderate profit over the past three years, with 6% recording a significant profit. About 20% broke even, 9% incurred a moderate loss, and 4% a significant loss.

In response to a question about the extent of involvement in businesses run by farmers groups, 48% said they are not at all involved, with 46% involved occasionally. Only 6% are involved at every opportunity. Almost half of respondents said that the farm business carried no debt. Nearly 39% said they were lightly in debt, and over 13% heavily in debt.

Only 14% of respondents had fixed costs below 20%, while 44% had fixed costs from 21-40%. Just over a fifth had fixed costs of over 40%, while a further fifth did not know the proportion of total annual farm costs that were fixed costs. When asked about the proportion of income from environmental schemes, almost three quarters indicated that these represented less than 5% of their income. For 10% of respondents environmental schemes contributed 20% or more of annual farm income.

In response to the question about the proportion of total income accounted for by the Single Farm Payment, 70% said that this represented less than 40% of their income, while for 20% it represented about half of their income. For 10% it represented more than half of their income.

Table III: Sample description based on farm operations

Farm operation parameters	Overall sample (n=150) Number of respondents	Percentage (%)
Annual value of total sales of agricultural produce	**136**	-
Less than £10,000	12	8.8
£10,001 to £50,000	30	22.1
£50,001 to £100,000	25	18.4
Over £100,000	69	50.7
Proportion of annual household income from farming	**142**	-
100%	76	53.5
About 75%	30	21.1
About 50%	13	9.2
About 25%	9	6.3
Below 25%	14	9.9
Over past three years has your farm made a profit or a loss?	**142**	-
Significant profit	9	6.3
Moderate profit	86	60.6
Break even	28	19.7
Moderate loss	13	9.2
Significant loss	6	4.2
Extent of involvement in businesses run by farmers groups	**142**	-
Not at all	68	47.9
Occasionally	65	45.8
At every opportunity	9	6.3
Farm business in debt	**139**	-
Not at all	66	47.5
Lightly	54	38.8
Heavily	19	13.7
Proportion of total annual farm costs that are 'fixed' costs	**139**	-
Less than 10%	6	4.3
10 - 20%	13	9.4
21 - 30%	34	24.5
31 - 40%	27	19.4
41 - 50%	13	9.4
Over 50%	17	12.2
Don't know	29	20.9
Proportion of farm income from environmental schemes	**145**	-
Less than 5%	106	73.1
Around 10%	24	16.6
Around 20%	8	5.5
Higher than 20%	7	4.8
Proportion of total income from Single Farm Payment	**145**	-
Less than 40%	101	69.7
Around half	29	20.0
More than half	15	10.3

The male and female respondents comprised 95 and 5 percent respectively of the sample (see Table IV). The mean age of respondents was 53 years. Almost half fell between the ages of 41 and 55, with 20% aged between 56 and 65, and 17% aged over 65. Sixteen percent of respondents were under 40.

In terms of the highest level of formal education attained, 23% have university degrees, with 41% having qualifications from technical colleges. The remaining 36% were educated to secondary school level.

In response to the question as to whether they see themselves as early adopters of technology, 40% indicated that they were. A further 40% said they were not early adopters, while the remaining 20% stated that they don't know.

Thirty-five percent of respondents had identified a successor to take over the farm, while just under half had not. The remaining 16% answered that they may have identified a successor.

Table IV: Sample description based on farmer traits

Farmer traits	Overall sample (n=150) Number of respondents	Percentage (%)	Mean, sem and median values
Gender	**142**	-	
Male	135	95.1	
Female	7	4.9	
Age	**127**	-	52.7 ± 1.0; 52 years
Up to 40 years	20	15.7	
41 - 55 years	60	47.2	
56 - 65 years	25	19.7	
>65 years	22	17.3	
Education status	**140**	-	
Secondary	51	36.4	
Technical College	57	40.7	
University	32	22.9	
Early adopter of technology?	**143**		
Yes	57	39.9	
No	58	40.6	
Don't know	28	19.6	
Have you identified a successor?	**142**		
Yes	50	35.2	
No	69	48.6	
Maybe	23	16.2	

Three of the farmers who responded are already growing SRC willow, with areas of 10, 34 and 53 hectares. Nine farmers are already growing miscanthus, with eight indicating the area of the crop. This ranged from 4ha to 60ha, with a mean of 20.6ha and a median of 17.5ha.

4.2 Behavioural intentions

When existing growers were asked whether they planned to plant more SRC willow on their farm, the farmer with 10ha said 'certainly not', the farmer with 53ha said 'probably not', while the farmer with 34ha was unsure. Of those already growing miscanthus, two were 'certainly not' going to plant more, two were 'probably not', and one was unsure. One farmer said he probably would, while two certainly would.

The key questions relating to behavioural intention asked farmers who were not already growing perennial energy crops 'Are you intending to plant SRC willow on your farm in the next 5 years?', and 'Are you intending to plant miscanthus on your farm in the next 5 years?'

The responses are shown in Figure 2. It can be seen that stated intentions towards the adoption of both crops are generally negative, with the means for both lying between 'certainly not' and probably not'. The stated intention towards miscanthus (mean -1.26) is slightly less negative than the stated intention towards SRC willow (mean -1.37).

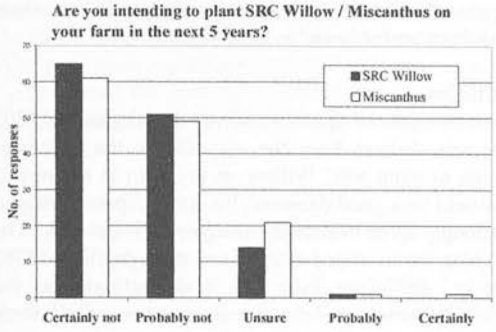

Figure 2: Behavioural intentions towards planting perennial energy crops

According to the TPB, behavioural intention is a reliable predictor of actual behaviour if at least one of the three main variables (attitude, subjective norm, or perceived behavioural control) correlates strongly with the stated intention. Table V shows that there is a strong correlation between intention to adopt SRC willow and all three variables. Thus behavioural intention towards SRC willow can be considered reliable, with stated attitude having the greatest influence on behavioural intention.

Table V: Correlation of main TPB variables with intention to adopt SRC willow

Are you intending to plant SRC Willow on your farm in the next 5 years?	Overall sample n=149	Correlation with intent (I)
Main TPB variables	Mean	r_s
Intention (I) (-2 to +2)	-1.37	
Stated attitude (SA) (-2 to +2)	-0.77	.586(**)
Subjective norm (SN) (-2 to +2)	-0.64	.440(**)
Perceived behavioural control (PBC) (-2 to +2)	-0.67	.440(**)
** Correlation is significant at the .01 level (1- tailed)		

For miscanthus, there are strong correlations between intention to adopt and all three main variables, as shown in Table VI. Thus behavioural intention towards miscanthus can be considered reliable, with stated attitude again having the greatest influence on behavioural intention, followed by perceived behavioural control.

Table VI: Correlation of main TPB variables with intention to adopt miscanthus.

Are you intending to plant Miscanthus on your farm in the next 5 years?	Overall sample n=149	Correlation with intent (I)
Main TPB variables	Mean	r_s
Intention (I) (-2 to +2)	-1.26	
Stated attitude (SA) (-2 to +2)	-0.67	.585(**)
Subjective norm (SN) (-2 to +2)	-0.51	.342(**)
Perceived behavioural control (PBC) (-2 to +2)	-0.57	.511(**)
** Correlation is significant at the .01 level (1- tailed)		

A Kruskal-Wallis analysis was undertaken to see if there is any significant difference in behavioural intention by any of the categories of farm characteristics, farm operations and farmer traits (see Tables II to IV). For SRC willow, significant differences existed in just two categories - farmland type and the extent of farm profit or loss. Table VII shows that for farmland type, using the Mann-Whitney U-test, there is a significant difference in adoption intention between 'all lowland', with a mean score of -1.45 (halfway between probably not and certainly not) and 'all upland', with a mean score of -0.5 (halfway between unsure and probably not).

Table VII: SRC willow adoption intentions by farmland type

	All lowland	Mostly lowland	Half and half	Mostly upland	All upland	
n	110	10	7	0	4	
	mean	mean	mean	mean	mean	K-W. Sig
Intention (-2 to +2)	-1.45	-1.20	-1.00	-	-0.50	.026
Mann-Whitney U-test significance values						
	All lowland	Mostly lowland	Half and half	Mostly upland	All upland	
All lowland		ns	ns	-	.010	
Mostly lowland	ns		ns	-	ns	
Half and half	ns	ns		-	ns	
Mostly upland	-	-	-		-	
All upland	.010	ns	ns	-		

Notwithstanding the small number of 'all upland' farms, in policy terms this does not seem to be immediately helpful as the adoption intention for 'all upland' farms is still negative, even if to a lesser extent than for 'all lowland' farms.

Table VIII: SRC Willow adoption intentions by extent of profit or loss

	Significant profit	Mod. profit	Break even	Mod. loss	Significant loss	
n	8	80	22	10	5	
	mean	mean	mean	mean	mean	K-W. Sig
	-1.75	-1.44	-1.00	-1.30	-2	.005
Mann-Whitney U-test significance values						
	Significant profit	Mod. profit	Break even	Mod. loss	Significant loss	
Significant profit		ns	.009	ns	ns	
Moderate profit	ns		.007	ns	.050	
Break even	.009	.007		ns	.004	
Moderate loss	ns	ns	ns		.034	
Significant loss	ns	.050	.004	.034		

Table VIII shows the significant differences in SRC willow adoption intentions between farms that recorded a significant loss (mean -2.00), and those who broke even (mean -1.00), or had a moderate profit (mean -1.44) or loss (mean -1.30). There are also significant differences between those who broke even and those where a moderate or significant profit (mean -1.75) was recorded. However the means of the adoption intentions by extent of profit or loss all fall between 'probably not' and 'certainly not'.

For miscanthus adoption intentions, a significant difference exists between those who consider themselves to be early adopters of technology (mean -1.29) and those who responded 'don't know' (mean -0.84). A further significant difference exists between those who do not consider themselves to be early adopters of technology (mean -1.41) and those who responded 'don't know'. However, there is no significant difference between those who responded 'yes' and those who responded 'no', and there are obvious practical difficulties in actually identifying those who don't know whether or not they are early adopters. Moreover, all three mean responses were negative, ranging from just below 'probably not', to nearly half-way between 'probably not' and 'certainly not'.

Table IX: Miscanthus adoption intentions by whether the farmer considers themselves to be an early adopter of technology.

	Yes	No	Don't know	
n	48	56	25	
	mean	mean	mean	K-W. Sig
Intention (-2 to +2)	-1.29	-1.41	-0.84	.022
Mann-Whitney U test significance values				
	Yes	No	Don't know	
Yes		ns	.037	
No	ns		.006	
Don't know	.037	.006		

There are also significant differences in miscanthus adoption intentions by the extent of farm profit or loss. Table X shows that significant differences exist between those recording a significant loss (mean -2.00) and those who broke even (mean -1.04) or made a moderate profit (mean -1.32) or loss (mean -1.10).

Table X: Miscanthus adoption intentions by extent of profit or loss.

	Significant profit	Mod. profit	Break even	Mod. loss	Significant loss	
n	8	81	23	10	5	
	mean	mean	mean	mean	mean	K-W. Sig
	-1.63	-1.32	-1.04	-1.10	-2	.041
Mann-Whitney U-test significance values						
	Significant profit	Mod. profit	Break even	Mod. loss	Significant loss	
Significant profit		ns	ns	ns	ns	
Moderate profit	ns		ns	ns	.029	
Break even	ns	ns		ns	.010	
Moderate loss	ns	ns	ns		.036	
Significant loss	ns	.029	.010	.036		

Again these are all negative adoption intentions ranging from 'probably not' to 'certainly not'.

4.3 Attitudes

Stated or general attitude towards the adoption of SRC willow was derived from the response to the statement 'Choosing to plant SRC Willow on my farm in the next 5 years would be a good decision'. Possible responses ranged from strongly agree to strongly disagree (See Table I). The mean value for the stated attitude towards adoption of SRC willow is -0.77 (see Table V). Stated attitude has the strongest influence on behavioural intention of all three main TPB variables (See Table V). In order to get a more detailed understanding of attitudes, respondents were asked to indicate their level of agreement/disagreement with a number of specific outcome beliefs that had arisen from the focus groups. They also had to indicate the level of importance attached to these outcomes.

Table XI: Outcome beliefs, outcome evaluations and attitudes towards the adoption of SRC willow

	Belief (-2 to +2)	Value (-2 to +2)	Attitude (-4 to +4)
	Mean	Mean	Mean
SRC Willow will give a high gross margin	-0.45	1.31	-0.62
Growing SRC Willow to contract will give me greater income security	-0.32	1.47	-0.35
Growing SRC Willow fits in with my current cropping plans	-0.89	1.15	-1.11
Growing SRC Willow to contract will give me greater stability of income	-0.43	1.21	-0.43
It is easy to do the paperwork required to grow SRC Willow to contract	-0.08	0.75	-0.17
SRC Willow roots will damage field drains	-0.42	1.05	-0.99
Growing SRC Willow will reduce the flexibility of the farm business	-0.5	1.03	-0.66
Growing SRC Willow is a good way for farmers to help tackle climate change	0.31	0.48	0.36
SRC Willow could be a good source of energy for local or on-farm use	0.3	-0.11	0.31
The likely costs and returns of SRC Willow are easy to calculate	-0.01	1.33	0.02
Growing SRC is a good opportunity to reduce the time spent on farming activities	0.22	0.09	0.09
Growing SRC Willow will disrupt my cashflow	-0.19	1.36	-0.35

Most of the outcome beliefs in Table IX are negative. For example, there is moderate disagreement (i.e. somewhere between unsure and disagree) that SRC willow will give a high gross margin. The outcome evaluations are mostly positive, indicating for example that getting a high gross margin lies somewhere between important and very important. Multiplying these scores through for each respondent gives a calculated attitude score for each statement. The three most negative attitudes relate to SRC willow not fitting in with current cropping plans, willow roots damaging field drains, and SRC willow reducing the flexibility of the farm business.

Of key importance in establishing the strength of these attitudinal influences on intention to adopt is the correlation with the stated intent. This shows (Table XII) that the most important attitudinal barriers to the adoption of SRC willow are the belief that growing SRC willow to contract will not give greater stability of income, followed by SRC willow not fitting in with current cropping plans. The next most significant are SRC willow roots damaging field drains, the lack of improved income security from SRC willow, reducing the flexibility of the farm business, and disrupting cashflow.

Table XII: Correlation between calculated attitudes and stated intention towards SRC willow.

	Attitude (-4 to +4)	Correlation with intent (I)
	Mean	r_s
SRC Willow will give a high gross margin	-0.62	.101
Growing SRC Willow to contract will give me greater income security	-0.35	.240(**)
Growing SRC Willow fits in with my current cropping plans	-1.11	.314(**)
Growing SRC Willow to contract will give me greater stability of income	-0.43	.342(**)
It is easy to do the paperwork required to grow SRC Willow to contract	-0.17	.004
SRC Willow roots will damage field drains	-0.99	.286(**)
Growing SRC Willow will reduce the flexibility of the farm business	-0.66	.220(**)
Growing SRC Willow is a good way for farmers to help tackle climate change	0.36	.058
SRC Willow could be a good source of energy for local or on-farm use	0.31	.067
The likely costs and returns of SRC Willow are easy to calculate	0.02	.020
Growing SRC is a good opportunity to reduce the time spent on farming activities	0.09	.063
Growing SRC Willow will disrupt my cashflow	-0.35	.217(**)

** Correlation is significant at the .01 level (1- tailed)

Interestingly, gross margin is not significantly correlated with intention to adopt SRC willow. This has important policy implications. It suggests that simply offering more money to farmers to grow SRC willow will not work unless a number of other 'preconditions' such as concerns over stability and security of income from contracts, as outlined above, are addressed.

Stated or general attitude towards the adoption of miscanthus was derived from the response to the statement 'Choosing to plant miscanthus on my farm in the next 5 years would be a good decision'. Possible responses ranged from strongly agree to strongly disagree (See Table I). The mean value for the stated attitude towards adoption of miscanthus is -0.67 (see Table V). As with SRC willow, stated attitude has the strongest influence on behavioural intention towards miscanthus of all three main TPB variables (See Table V). Again in order to get a more detailed understanding of attitudes towards adoption of miscanthus, respondents were asked to indicate their level of agreement/disagreement with a number of specific outcome beliefs that had arisen from the focus groups.

Most of the outcome beliefs (See Table XIII) for miscanthus are negative, although farmers are unsure/mildly disagree that they will damage field drains. The outcome evaluations are identical to those previously recorded for SRC willow as these questions were combined in the interest of brevity. Again, multiplying these scores through for each respondent gives a calculated attitude for each statement.

Table XIII: Outcome beliefs, calculated attitudes, and correlation between calculated attitudes and stated intention towards miscanthus.

	Belief (-2 to +2)	Attitude (-4 to +4)	Correlation with intent (I)
	Mean	Mean	r_s
Miscanthus will give a high gross margin	-0.35	-0.46	.158(*)
Growing Miscanthus to contract will give me greater income security	-0.12	-0.01	.329(**)
Growing Miscanthus fits in with my current cropping plans	-0.63	-0.8	.423(**)
Growing Miscanthus to contract will give me greater stability of income	-0.25	-0.22	.456(**)
It is easy to do the paperwork required to grow Miscanthus to contract	-0.04	-0.13	.064
Miscanthus roots will damage field drains	0.12	-0.12	.130
Growing Miscanthus will reduce the flexibility of the farm business	-0.25	-0.29	.103
Growing Miscanthus is a good way for farmers to help tackle climate change	0.31	0.39	.150(*)
Miscanthus could be a good source of energy for local or on-farm use	0.29	0.26	.073
The likely costs and returns of Miscanthus are easy to calculate	0.05	0.15	.156(*)
Growing Miscanthus is a good opportunity to reduce the time spent on farming activities	0.2	0.15	.016
Growing Miscanthus will disrupt my cashflow	-0.26	-0.43	.144

** Correlation is significant at the .01 level (1- tailed)

* Correlation is significant at the .05 level (1- tailed)

The three most negative attitudes relate to miscanthus not fitting in with current cropping plans, not having a high gross margin, and disrupting cashflow. Again it is important to establish the strength of these influences on intention to adopt. The final column of Table XIII shows that the most significant attitudinal barriers to adoption for miscanthus are the belief that growing miscanthus to contract will not give greater stability of income, followed by miscanthus not fitting in with current cropping plans, and not increasing income security. Less significant correlations include miscanthus not having a high gross margin.

4.4 Subjective norm

Stated or general subjective norm towards the adoption of SRC willow was derived from the response to the statement 'People whose opinions I value think I should plant SRC willow on my farm in the next five years'. Possible responses ranged from strongly agree to strongly disagree (See Table I). The mean value for the stated subjective norm towards adoption of SRC willow is -0.64 (see Table V). Stated subjective norm is strongly correlated with behavioural intention, with an influence on behavioural intention equal to that of perceived behavioural control but less than that of stated attitude (See Table V).

A key part of any agricultural knowledge transfer strategy is to identify appropriate channels for communicating with farmers about specific new policies or techniques [24]. These trusted sources of advice and influence can be identified by using the TPB. A number of salient referents were identified in the focus groups, and respondents to the questionnaire were asked to indicate the extent to which these referents would approve or disapprove of them growing SRC willow on their farms in the next five years (subjective belief). They were also asked how likely it was that they would follow the advice of these referents in relation to the adoption of these perennial energy crops (motivation to comply).

Table XIV: Mean subjective belief, motivation to comply, subjective norm for salient referents with regard to the adoption of SRC willow, and correlation of referent subjective norm with intent.

	Subjective belief (-2 to +2)	Motivation to comply (-2 to +2)	Subjective norm (-4 to +4)	Correlation with intent (I)
	Mean	Mean	Mean	r_s
Would the following approve or disapprove of you growing SRC Willow?				
Farmers clubs	-0.04	-0.61	0.19	-.019
Existing SRC growers	0.45	-0.12	0.15	.152
Other farmers	-0.13	-0.16	0.35	-.107
SRC Producer groups	0.63	-0.17	0.07	.168(*)
Power companies	0.7	-0.47	-0.28	.253(**)
Farming press	0.41	-0.37	-0.03	.160(*)
Defra	0.51	-0.47	-0.15	.158(*)
Biomass Energy Centre	0.88	-0.24	-0.11	.200(*)
NFU	0.29	-0.35	0.1	.027
Agronomist	-0.25	0	0.1	.093
Own experience / judgement	-0.32	0.28	-0.03	.112
Family	-0.32	0.01	0.05	-.031
Members of the public	0.28	-0.9	-0.15	.019

** Correlation is significant at the .01 level (1- tailed)

* Correlation is significant at the .05 level (1- tailed)

The subjective beliefs listed in Table XIV show that, as might be expected, farmers think that those who would most strongly approve of them growing SRC willow are the Biomass Energy Centre (mean 0.88), power companies (mean 0.70), SRC producer groups (mean 0.63), and Defra (mean 0.51).

Still with a positive mean, but closer to 'unsure' than 'approve', are existing SRC growers (mean 0.45), farming press (mean 0.41), NFU (mean 0.29) and members of the public (mean 0.28). Negative means, moving from 'unsure' towards 'disapprove' were obtained for farmers clubs (mean -0.04), other farmers (mean -0.13), agronomist (mean -0.25), and own experience/judgement and family both with a mean of -0.28.

What is particularly interesting is the motivation to comply with the various salient referents, which tends to be negative, but not strongly. This would support the findings from the focus groups [30] that farmers are sceptical of certain interests, that there is a need for clear, unbiased information, and that farmers really don't know where to turn for advice on perennial energy crops. Indeed the mean for own experience/judgement (0.28) suggests that farmers do not have confidence in their own judgement on perennial energy crops. The least negative means, following own experience/judgement and family are agronomist (mean 0), existing SRC growers (mean -0.12), other farmers (mean -0.16) and SRC producer groups (mean -0.17). This would suggest that the current practice of farm open days, where prospective adopters view SRC willow being grown and harvested are a relatively effective way of getting information across.

Multiplying through the scores for subjective belief and motivation to comply for each individual we get the referent subjective norm. Looking at the correlation of the referent subjective norms with intent in isolation, one might be forgiven for thinking that power companies are the best channel for extending information to potential growers of SRC willow. However, as we have seen, this strong correlation with intent is in fact due to the negative motivation to comply with a referent who approves of an activity that the majority of respondents do not in fact plan to undertake.

Stated or general subjective norm towards the adoption of miscanthus was derived from the response to the statement 'People whose opinions I value think I should plant miscanthus on my farm in the next five years'. Possible responses ranged from strongly agree to strongly disagree (See Table I). The mean value for the stated subjective norm towards adoption of miscanthus is -0.51 (see Table VI). Stated subjective norm is strongly correlated with behavioural intention, but with an influence on behavioural intention less than that of both perceived behavioural control and stated attitude (See Table VI).

Respondents to the questionnaire were asked to indicate the extent to which the salient referents would approve or disapprove of them growing miscanthus on their farms in the next five years (subjective belief). Their motivations to comply with these salient referents are identical to those previously recorded for SRC willow as these questions were combined. This followed feedback from the pilot survey where it was identified that the questionnaire was too long.

The subjective beliefs listed in Table XV show that, again as might be expected, farmers think that those who would most strongly approve of them growing miscanthus are the Biomass Energy Centre (mean 0.78), power companies (mean 0.70), and miscanthus producer groups (mean 0.65).

Still with a positive mean, but closer to 'unsure' than 'approve', are Defra (mean 0.49), existing miscanthus growers (mean 0.43), farming press (mean 0.33), NFU (mean 0.24) members of the public (mean 0.08), and farmers clubs (0.03). Negative means, moving from 'unsure' towards 'disapprove' were obtained for other farmers (mean -0.01), agronomist (mean -0.17), family (mean of -0.21), and own experience/judgement with a mean of -0.22.

These subjective beliefs are very close to those given for SRC willow, and underline the uncertainty as to what farmers believe many referents actually think about the adoption of perennial energy crops.

Table XV: Mean subjective belief, motivation to comply, subjective norm for salient referents with regard to the adoption of miscanthus, and correlation of referent subjective norm with intent.

	Subjective belief (-2 to +2)	Motivation to comply (-2 to +2)	Subjective norm (-4 to +4)	Correlation with intent (I)
	Mean	Mean	Mean	r_s
Would the following approve or disapprove of you growing Miscanthus?				
Farmers clubs	0.03	-0.61	0.16	-.019
Existing Miscanthus growers	0.43	-0.12	0.33	.152
Other farmers	-0.01	-0.16	0.35	-.107
Miscanthus producer groups	0.65	-0.17	0.2	.168(*)
Power companies	0.70	-0.47	-0.17	.253(**)
Farming press	0.33	-0.37	0.02	.160(*)
Defra	0.49	-0.47	-0.08	.158(*)
Biomass Energy Centre	0.78	-0.24	-0.02	.200(*)
NFU	0.24	-0.35	0.14	.027
Agronomist	-0.17	0	0.3	.093
Own experience/judgement	-0.22	0.28	0.08	.112
Family	-0.21	0.01	0.15	-.031
Members of the public	0.08	-0.90	0.02	.019
** Correlation is significant at the .01 level (1- tailed)				
* Correlation is significant at the .05 level (1- tailed)				

Multiplying through the scores for subjective belief and motivation to comply for each individual we get the referent subjective norm. Looking at the correlation of the referent subjective norms with intent in isolation, it again appears that power companies are the best channel for extending information to potential growers of miscanthus. However, once more this strong correlation with intent is in fact due to the negative motivation to comply with a referent who approves of an activity that the majority of respondents do not in fact plan to undertake.

4.5 Perceived behavioural control

Perceived behavioural control in respect of the adoption of SRC willow was obtained from the mean value of responses to two statements relating to difficulty and ability. The first was 'How difficult would it be to grow SRC willow on your farm in the next 5 years?'. Possible responses ranged from very difficult to very easy (See Table I). The second was 'How confident are you of being able to grow SRC willow on your farm in the next 5 years?'. Possible responses ranged from very confident to not at all confident (See Table I).

The mean value for perceived behavioural control in respect of the adoption of SRC willow is -0.67 (see Table V). This correlates strongly with stated intent, and exerts a similar level of influence on intent as stated subjective norm, but less influence on intent than stated attitude (See Table V).

When the two components of perceived behavioural control in respect of the adoption of SRC willow are viewed independently (See Table XVI), farmers see growing SRC willow as moderately difficult (mean -0.38), but when it comes to confidence in their ability to grow it, they are not very confident (mean -0.97). Both ability and difficulty are strongly correlated with behavioural intent, with ability exerting the stronger influence.

Table XVI: Mean scores for PBC, Difficulty and Ability in respect of the adoption of SRC Willow, and correlation with intent.

Are you intending to plant SRC Willow on your farm in the next 5 years?	Overall sample n=149	Correlation with intent (I)
Main TPB variables	Mean	rs
Intention (I) (-2 to +2)	-1.37	
PBC (-2 to +2)	-0.67	.440(**)
Difficulty	-0.38	.301(**)
Ability	-0.97	.501(**)
** Correlation is significant at the .01 level (1- tailed)		

These results would appear to support the view from the focus groups that specialist contractors would be needed for SRC establishment and harvesting due to the requirement of specialist equipment [30].

Perceived behavioural control in respect of the adoption of miscanthus was obtained in the same way - from the mean value of responses to two statements relating to difficulty and ability. The first was 'How difficult would it be to grow miscanthus on your farm in the next 5 years?'. Possible responses ranged from very difficult to very easy (See Table I). The second was 'How confident are you of being able to grow miscanthus on your farm in the next 5 years?'. Possible responses ranged from very confident to not at all confident (See Table I).

The mean value for perceived behavioural control in respect of the adoption of miscanthus is -0.57 (see Table VI). This correlates strongly with stated intent, and exerts more influence on intent than stated subjective norm, but slightly less influence on intent than stated attitude (See Table VI).

When the two components of perceived behavioural control in respect of the adoption of miscanthus are viewed independently (See Table XVII), farmers see growing miscanthus as moderately difficult (mean -0.35), but when it comes to confidence in their ability to grow it, they are not very confident (mean -0.81). Both ability and difficulty are strongly correlated with behavioural intent, with ability exerting the stronger influence.

Table XVII: Mean scores for PBC, Difficulty and Ability in respect of the adoption of miscanthus, and correlation with intent.

Are you intending to plant Miscanthus on your farm in the next 5 years?	Overall sample n=149	Correlation with intent (I)
Main TPB variables	Mean	rs
Intention (I) (-2 to +2)	-1.26	
(PBC) (-2 to +2)	-0.57	.511(**)
Difficulty	-0.35	.387(**)
Ability	-0.81	.578(**)
** Correlation is significant at the .01 level (1- tailed)		

5 DISCUSSION

While it is fairly common for farmers not to admit to outside sources of influence in open discussion [28], other postal surveys have elicited a number of positive mean sources of influence [24, 27]. This reinforces the perception from the focus groups [30] that farmers don't know who to turn to for advice on perennial energy crops. However, the mean values do not tell the whole story. Table XVIII lists the number who indicated that they would be likely or highly likely to follow the advice of specific salient referents.

Table XVIII: The number of respondents indicating that they would be likely or highly likely to follow the advice of specific salient referents.

Own experience/judgement	55
Agronomist	45
Existing SRC willow / miscanthus growers	41
Family	41
Other farmers	38
SRC willow / miscanthus producer groups	35
Biomass Energy Centre	33
NFU	29
Defra	26
Farming press	24
Power companies	23
Farmers clubs	15
Members of the public	10

It can be seen that in terms of non-family referents, the five most likely sources of advice are agronomists, existing SRC willow/miscanthus growers, other farmers, SRC willow/miscanthus producer groups, and the Biomass Energy Centre. This tends to support findings from the focus groups [30] that site visits and talking to existing growers are good ways of obtaining information, as is sharing information with other farmers through producer groups and co-operatives. It was thought by focus group participants that the Biomass Energy Centre had the potential to become a trusted source of information [30]. To this can be added the suggestion that involving agronomists in open days organised by existing growers and producer groups would seem to be a reasonable way of promoting knowledge transfer among potential adopters.

Farmers do not, in general, seem to know a great deal about perennial energy crops. In response to the question of whether SRC willow will give a high gross margin, 64% were unsure, and for miscanthus, 67% were unsure. Unsurprisingly, in answer to the question of whether the likely costs and returns of SRC willow are easy to calculate, 80% were unsure, and 72% unsure for miscanthus. Likewise 85% were unsure whether the paperwork required to grow SRC willow to contract was easy, with 79% unsure about the paperwork required for miscanthus.

The finding that gross margin is not significantly correlated with behavioural intent for SRC willow, and is less significantly correlated than a number of other attitudinal factors for miscanthus is of importance for policy makers. It suggests that simply increasing the gross margin for perennial energy crops will not be an effective way of encouraging increased farmer uptake unless a number of issues such as those relating to security and stability of income from contracts are addressed. The proposed banding of the Renewables Obligation [21], intended to give a greater financial reward to those growing perennial energy crops, may not therefore bring about an increase in adoption unless the issues mentioned above are addressed at the same time.

6 CONCLUSION

It seems unlikely that the theoretical potential of perennial energy crops in the UK will be realised unless a number of barriers to adoption are overcome. For both SRC willow and miscanthus, these include concerns about the security and stability of income from contracts. Specifically in relation to SRC willow, farmers have concerns over disruption to cashflow, reduction in the flexibility of the farm business, and damage to field drains from willow roots.

While farmers in general don't consider that miscanthus or SRC willow will give a high gross margin, simply increasing the financial return from these crops without addressing the concerns outlined above is unlikely to result in widespread uptake.

In terms of further research, farm-level mathematical programming techniques will be used to identify the level of uptake that might be expected at different gross margins if the barriers identified in this paper are overcome, and assuming profit maximisation as the objective.

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8 REFERENCES

[1] Defra, UK Biomass Strategy. Department for Environment, Food and Rural Affairs. May 2007.

[2] Council of the European Union, Presidency Conclusions, Brussels European Council, 8/9 May 2007.

[3] RCEP, Biomass as a Renewable Energy Source; a limited report by the Royal Commission on Environmental Pollution, 2004.

[4] DTI, Renewables Innovation Review, Department of Trade and Industry, 2003.

[5] Carbon Trust, Biomass sector review for the Carbon Trust, October 2005

[6] ADAS, The mid-term evaluation of the England Rural Development Programme (ERDP): energy crop scheme, 2003.

[7] Defra, Creating value from renewable materials: a strategy for non-food crops and uses - two year progress report, Department for Environment, Food and Rural Affairs, 2006.

[8] SAC, Commercial viability of alternative non-food crops and biomass on Scottish farms - a special study supported under SEERAD Advisory Activity 211, March 2007.

[9] DARDNI, Renewable Energy Action Plan. Department of Agriculture and Rural Development, Northern Ireland, January 2007.

[10] Welsh Assembly Government. Personal communication from Vicky Davies, Rural Development Adviser, Technical Services Division, Welsh Assembly Government, Llandrindod Wells, 2007.

[11] Rosenqvist, H., Dawson, M., Economics of willow growing in Northern Ireland, Biomass and Bioenergy 28, 7-14, 2005.

[12] Skytte, K., Meibom, P., Capral Henriksen, T., Electricity from biomass in the European Union - with or without biomass import? Biomass and Bioenergy 30, 385-392, 2006.

[13] Charles, M.B., Ryan, R., Ryan, N., Oloruntoba, R. Public policy and biofuels: the way forward? Energy Policy 35, 5737-5746, 2007.

[14] Andersen, R.S., Towers, W., Smith, P., Assessing the potential for biomass energy to contribute to Scotland's renewable energy needs. Biomass and Bioenergy 29, 73-82, 2005.

[15] Ericsson, K., Nilsson, L., Assessment of the potential biomass supply in Europe using a resource-focused approach. Biomass and Bioenergy 30, 1-15, 2006.

[16] Styles, D., Jones, M.B., Current and future financial competitiveness of electricity and heat from energy crops: a case study from Ireland. Energy Policy 35, 4355-4367, 2007.

[17] Upham, P., Speakman, D., Stakeholder opinion on constrained 2030 bioenergy scenarios for North West England. Energy Policy 35, 5549-5561, 2007.

[18] Strawson, J., Energy crops and the market for biomass in the UK. Nuffield Farming Scholarships Trust, January 2005.

[19] FAO, Crop prospects and food situation, No. 5, Food and Agriculture Organisation of the United Nations, Rome, October 2007.

[20] European Commission, Cereals: council approves zero set-aside rate for autumn 2007 and spring 2008 sowings, Press release, September 2007.

[21] DTI, Renewable energy: reform of the Renewables Obligation. Department for Trade and Industry, May 2007.

[22] Ajzen, I., Fishbein, M., Attitudes, Personality and Behaviour. Open University Press, Milton Keynes, 1980.

[23] Ajzen, I., The Theory of Planned Behaviour, Organizational Behaviour and Human Decision Processes 50, 179-211, 1991.

[24] Garforth, C., Rehman, T., McKerney, K., Tranter, R.B., Cooke, R.J., Yates, C.M., Park, J.R., Doward, P.T., Improving the design of knowledge transfer strategies by understanding farmer attitudes and behaviour, Journal of Farm Management 12, 17-32, 2004.

[25] Beedell, J., Rehman, T., Using social-psychology models to understand farmers' conservation behaviour, Journal of Rural Studies 16, 117-127, 2000.

[26] Defra, Research to understand and model the behaviour and motivations of farmers in responding to policy changes (England) - Application and impact of the Single Payment Scheme: a Theory of Planned Behaviour analysis. Project Report no. 6, Research project EPES 0405/17, June 2006.

[27] Mattison, E.H.A., Norris, K., Intentions of UK farmers toward biofuel crop production: implications for policy targets and land use change, Environmental Science and Technology 41 (16), 5589-5594, 2007.

[28] Burton, R.J.F., Reconceptualising the 'behavioural approach' in agricultural studies: a socio-psychological perspective, Journal of Rural Studies 20, 359-371, 2004.

[29] Eagly, A. Chaiken, S., The Psychology of Attitudes, Harcourt Brace Jovanovich, San Diego, 1993.

[30] Sherrington, C., Bartley, J., Moran, D., Farm-level constraints on the domestic supply of perennial energy crops in the UK, Energy Policy (in press)

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Modelling farmer uptake of perennial energy crops in the UK

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The UK Biomass Strategy suggests that to reach the technical potential of perennial energy crops such as short rotation coppice (SRC) willow and miscanthus by 2020 requires 350,000 hectares of land. This represents a more than 20-fold increase on the current 15,546 hectares. Previous research has identified several barriers to adoption, including concerns over security of income from contracts. In addition, farmers perceive returns from these crops to be lower than for conventional crops. This paper uses a farm-level linear programming model to investigate theoretical uptake of energy crops at different gross margins under the assumption of a profit-maximising decision maker, and in the absence of known barriers to adoption. The findings suggest that while SRC willow, at current prices, remains less competitive, returns to miscanthus should have encouraged adoption on a wider scale than at present. This highlights the importance of the barriers to adoption. Recently announced contracts for miscanthus appear to offer a significant premium to farmers in order to encourage them to grow the crops. This raises the question of whether a more cost-effective approach would be for government to provide guarantees addressing farmers concerns including security of income from the contracts. Such an approach should encourage adoption at lower gross margins.

1. Introduction

In seeking both to tackle climate change and ensure that the UK has a secure supply of affordable energy, the UK Government is proposing a significant expansion in the generation of energy from renewable sources (DECC, 2009a). Under the Renewable Energy Directive, the UK is committed to the EU wide target to source 20% of the EU's total energy use from renewable sources by 2020. The UK's contribution towards this target is to provide renewable sources for 15% of its total energy use by 2020 (European Parliament and Council of the European Union, 2009). This would represent a ten-fold increase in levels of renewable generation over the next 12 years. The UK Government's Renewable Energy Strategy, which outlines how this level of generation could be achieved indicates that around 30% of the UK renewable energy target could come from biomass (DECC, 2009a).

The term 'biomass' covers a range of renewable fuels derived from organic matter, of which there are a number of possible sources in the UK. These include landfill gas, sewage gas, forestry, wood waste, conventional agricultural crops such as wheat and oilseed rape, straw, perennial energy crops, and agricultural waste (RCEP, 2004; Defra, 2007).

To increase available biomass, Defra (2007) favours obtaining an additional 1 million dry tonnes of wood per annum from woodland and wood waste, more use of manures and slurries, and a substantial growth in the uptake of perennial energy crops such as short rotation coppice (SRC) willow and miscanthus. Of these sources, it is the anticipated change in levels of perennial energy crops that is most dramatic, from under 16,000 hectares (ha) at present to 350,000 ha by 2020. This represents approximately a 20-fold increase, and would occupy roughly 6.5% of UK arable and set-aside land (Defra, 2007). The Renewable Energy Strategy is even more ambitious, with a supporting annex, looking at both arable and pasture land suggesting that the potential could be up to 2.2 million ha by 2030 (E4Tech, 2009).

Perennial energy crops can be considered as a novel enterprise for UK farmers, both in terms of their cultivation, and in their position at the interface between agricultural and energy policy. This brings a greater number of uncertainties than exist with conventional agricultural activities (Sherrington et al., 2008), and a number of financial and non-financial barriers to the adoption of such crops by UK farmers have been identified. These include concerns over the security and stability of income from contracts, disruption to cashflow, and reduced farm business flexibility (Sherrington et al., 2008; Sherrington and Moran, 2008). This paper builds on existing understanding by using a farm-level linear programming model to investigate theoretical uptake in energy crops at different gross margins (revenue minus variable costs) under the assumption of a profit-maximising decision maker, and in the absence of known barriers to adoption. The findings suggest that SRC willow at current prices remains unattractive for most farm types purely on a gross margin basis,

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even before accounting for concerns such as the impact of roots on field drains, and the security of the contracts available, although potential does exist for greater financial returns as the market for heat from SRC willow develops. Miscanthus, however, is currently more attractive on a gross margin basis, and the modelling suggests that adoption should, in theory, be widespread. There are fewer non-financial barriers to the adoption of miscanthus than SRC willow (Sherrington et al., 2008), and prices now available on contracts to supply miscanthus for co-firing at the UK's largest coal fired power station (Farmers Weekly, 2008; Farmers Guardian, 2008) make this crop considerably more attractive.

The paper is structured as follows. The next section compares estimates of the theoretical potential of perennial energy crops with actual uptake to date, before reviewing current understanding of barriers to energy crop adoption. The methodology for application of the linear programming model and its inputs are then described, and the results at the farm-level, and on aggregate, subsequently presented. A discussion section considers the results in the context of support for energy crops through energy and agricultural policies, and through contracts. A number of issues of policy significance are highlighted, followed by some recommendations and concluding comments.

2. Theoretical potential of energy crops in the UK

The theoretical potential of energy crops is estimated by Defra to be 17.2 TWh[1] (1.48 Mtoe)[2] per annum, while current availability is 0.07–0.09 Mtoe per annum (Defra, 2007). To reach this potential by 2020 would require 350,000 ha of land, which is roughly 6.5% of UK arable and set-aside land, assuming an average annual yield of 9 oven dried tonnes (odt) per hectare (Defra, 2007). The Renewables Innovation Review (DTI, 2003), the original source of the above theoretical potential, suggests this is a realistic area once a number of constraints, including competition from other markets, are taken into account.

A recently developed range of energy crop scenarios used to inform the Renewable Energy Strategy suggests that by 2030, using both arable and pasture land, the potential could be up to 2.2 million ha (E4Tech, 2009).

However, the actual realisation of the potential for these crops depends upon farmer behaviour—whether or not individual farmers choose to grow SRC willow and/or miscanthus. Experience to date suggests that farmer behaviour could be an important constraint on realising widespread uptake, on the scale identified by the estimates above.

Defra's Energy Crops Scheme, which provides establishment grants for SRC willow and miscanthus, was intended to support the planting, by 2006, of 16,700 ha of SRC and 5000 ha of miscanthus in England (ADAS, 2003). When the scheme closed to applications, in July 2006, only 1180 ha of SRC and 3356 ha of miscanthus had been planted, however, increased interest in the payments, saw applications for planting in 2007 set to take the area of miscanthus to 12,627 ha, and SRC to 2600 ha in England (Defra, 2006).

In Scotland, the area planted or approved for planting up until the end of 2006 was 300 ha, with applications for planting in 2007 and 2008 amounting to around 600 ha (SAC, 2007a). In Northern Ireland, 810 ha of SRC have been planted or approved for planting (DARDNI, 2007), while in Wales there is known to be 40 ha of SRC and 72 ha of miscanthus (Welsh Assembly Government, 2007).

The latest published figure for the total area of perennial energy crops in the UK is 15,546 ha for SRC willow and miscanthus combined (Defra, 2007), however it is believed that the planted area is now around 17,000 ha (RELU, 2009).

3. Farmer attitudes and intentions towards the adoption of perennial energy crops

Focus group research involving existing and potential growers of SRC willow and miscanthus (Sherrington et al., 2008) revealed a broad consensus that the principle factor affecting a farmer's decision whether or not to grow perennial energy crops was perception of the level, and the security, of the financial return.

Of key importance to focus group participants was the establishment grant. Very few would consider growing perennial energy crops in the absence of the grant, due to high upfront costs and uncertainties over the resulting net income (Sherrington et al., 2008). However, the establishment grant has since been reduced from £1000/ha to a typical level of £665/ha for SRC willow, and from £920 to £800/ha for miscanthus (Jones, 2007). From the perspective of farmers taking part in the focus groups, this would make the crops less attractive.

Farmers felt that the lack of an incentive for renewable heat was a significant barrier to the development of energy crop supply, particularly for SRC willow. There was a keen awareness that the financial return could be greater if farmers were supplying local schools, hospitals or leisure centres. It was felt that supply to large electricity generators would never be the most financially attractive option. This view is supported by Valentine et al. (2008), who consider that SRC willow is currently undervalued, and that higher prices should be achievable as the market develops and the inherent energy value is fully recognised.

Follow up research (Sherrington and Moran, 2008) in the form of a wider postal survey of UK farmers' attitudes and behavioural intentions towards perennial energy crops identified that perception of financial return was not simply a question of anticipated gross margin. Of greater concern was the security and stability of income from contracts, disruption to cashflow, and reduced farm business flexibility. Specifically in relation to SRC willow, there were worries about damage to field drains from the roots.

The opportunity cost of growing perennial energy crops was also a concern to focus group participants. While the price of wheat and other annual crops has increased dramatically in recent years, the price offered for SRC willow and miscanthus was not felt to have risen much at all (Sherrington et al., 2008). Moreover, farmers are familiar with annual crops, for which there is a well developed market. While farmers may not always get the price they are expecting with wheat, they know they will at least be able to sell it, whereas for perennial energy crops, the lack of a developed market means farmers are concerned about being left with a crop that no-one will buy. The majority of focus group participants felt it was difficult to calculate the returns from energy crops due to uncertainty over costs, yields, and prices. In contrast, farmers were very aware of returns from conventional annual crops and at what prices and yields they would be profitable (Sherrington et al., 2008). There is also the issue of flexibility, with farmers valuing the ability to switch crops year on year—something that would not be possible on land committed to perennial energy crops (Sherrington et al., 2008).

University of Cambridge (2005) identifies that farmers are often reluctant to switch from one annual crop with which they are familiar to another less familiar annual crop. This inertia means that farmers may not immediately switch on the basis of an increased gross margin. For miscanthus and SRC willow the

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[1] Terawatt hours (one teraWatt is a trillion, or 10^{12} Watts).

[2] Million tonnes of oil equivalent.

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differences are greater still. SAC (2007a) states that for most farm businesses SRC willow remains unattractive due to the long term commitment required, loss of cropping flexibility, and limited market. It is suggested that to overcome these issues and achieve large scale plantings, SRC willow returns would have to significantly exceed those achievable in conventional arable systems (SAC, 2007a).

However, estimating the required level of return is very difficult as the risks involved in growing perennial energy crops are of a different kind to those associated with annual crops. Comparison of two annual crops might be based on their average yield and price over a number of years, and the variance of those factors, with a higher variance indicating a greater risk. For perennial energy crops there is no such track record of yield and price to which farmers can refer with confidence. Indeed, along with yield and price risk, there is regulatory risk, arising from both agricultural and energy policy. The suspension of the establishment grant and the subsequent lowering of the payment level is an example of the former, while ongoing amendments as to the status of co-firing within the RO (Sherrington et al., 2008), and subsequent banding of ROCs (OPSI, 2009) are examples of the latter. There is also institutional risk, in terms of the confidence that farmers have in the security of payments available through contracts (Sherrington et al., 2008).

While difficult to model, the fact that farmers' perceptions of the risks associated with perennial energy crops have been identified is an important step. As Meijer et al. (2007) point out, identifying dominant sources of uncertainty can deliver valuable insights for policy makers, who may choose to act to tackle these barriers to adoption. Sherrington et al. (2008), for example, suggest that farmer confidence in the security of the contracts could be increased through government underwriting or some form of insurance.

This paper therefore abstracts from these uncertainties, and looks at the level of financial return required to motivate farmers to adopt perennial energy crops under the assumption of a profit maximising decision maker, and in the absence of previously identified barriers.

4. Methodology for application of the farm level model

A generic linear programming model for farm-level analysis, developed at the Scottish Agricultural College (SAC) was used to assess the likely uptake of perennial energy crops at different gross margins under the assumption of a profit maximising decision maker, as outlined above. The model can be calibrated to represent any particular farm situation, in terms of basic resource endowments, and run using Visual Basic for Applications and Microsoft Excel Solver to simulate representative or real farm situations. The model has been used in various studies, e.g. Revell and Oglethorpe (2003), to analyse the economic impacts of policy developments on farm businesses, particularly relating to how enterprise substitutions may occur. The model incorporates all major cropping and livestock activities carried out on UK farms and can thus be calibrated for all mainstream farming types (University of Cambridge, 2005). The objective function of the model is to maximise the overall farm gross margin (revenue minus variable costs) in a single year (SRC willow and miscanthus gross margins are therefore represented as annual equivalent values) within the constraints of available resources such as land, labour, and machinery.

Gross margins are not explicitly entered into the model for conventional crops, but are implicit from the variable costs involved in production, relating for example to seeds, fertiliser, and herbicides, and the revenue based on the yield and the prices received. For the purposes of this exercise, energy crops are included in the model as an extra activity available to the farmer. This energy crop option does have an explicit gross margin. The model proceeds through a number of runs, with the objective of maximising the whole farm gross margin. With each run of the model, the gross margin attributed to energy crops is gradually increased, and the effect of this on the amount of land allocated to energy crops is observed. Having identified the gross margin that is necessary to bring about a certain level of uptake, the price/yield/subsidy combination necessary to achieve such a gross margin is considered.

Fixed costs are included in the modelling in order to calculate a net margin for SRC and miscanthus, but the allocation of land to energy crops in the model is determined simply by the energy crop's gross margin. It is considered likely that for most farmers the establishment and harvesting of perennial energy crops will be undertaken by contractors (University of Cambridge, 2005; Sherrington et al., 2008), and this is reflected in the model where these activities make no call on the farm's labour or machinery resources. For conventional crops, however, farms have a choice of using on-farm machinery and labour, which is effectively a fixed-cost aspect, or alternatively, once these resources are fully allocated, contractors and related machinery can be brought in. It is worth noting that the use of contractors for conventional crops represents a variable cost attributed to the specific activity, and will therefore reduce the gross margin of that particular activity.

It was decided not to attempt explicitly to consider risk within the model because, as outlined above, the risks associated with growing perennial energy crops are different from those related to conventional crops. In addition to potential variations in price and yield, a number of specific concerns stem from the position of perennial energy crops at the interface of agricultural and energy policy. Alongside this changing regulatory framework is the perceived institutional risk associated with contracts. The approach taken, therefore, is to abstract from these previously identified risks (Sherrington et al., 2008; Sherrington & Moran, 2008) and examine theoretical uptake under the assumption that these barriers to adoption had effectively been tackled through policy intervention.

The model was used by University of Cambridge (2005) to predict uptake of perennial energy crops at different gross margins across four of the major farm types (cereal farms, mixed farms, general cropping farms, cattle and sheep (lowland) farms). However, in the context of the subsequent significant global rise in the price of agricultural commodities such as wheat (FAO, 2007; Farmers Weekly, 2009b) and the role that biomass is due to play in the UK Government's approach to tackling climate change (DECC, 2009a) it is important to reassess the gross margins that would be required to stimulate production to the level necessary to meet the theoretical potential. The four representative farm types are distinguished in the model principally on the basis of the number of hectares of different land types available for different activities. As in the University of Cambridge (2005) study, each of the farm types were split into three size groups based on classifications from the Farm Accounts in England (Defra, 2002) (see Table 1). As with the University of Cambridge (2005) study, within the model energy crop production can only occur on tillable land. It is recognised that this is a simplification in that some farmers may choose to plant perennial energy crops on less productive soils, although the yield and therefore gross margin would be lower in these cases.

With an increase in agricultural commodity prices over the past few years, UK farmers are now achieving higher gross margins for a number of conventional crops. A typical gross margin for winter wheat, for example, has increased from £301/ha (University of Cambridge, 2005) to £738/ha (SAC, 2007b). While

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Table 1
Farm types used in modelling exercise.

Farm type	Size	Total area farmed (ha)	Semi-natural pasture/rough grazing (ha)	Permanent pasture (ha)	Tillable land (ha)
Cereal	Small	60	0.5	8.7	50.8
	Medium	143	1.1	13.5	128.4
	Large	392	1.2	21.5	369.3
Mixed	Small	90	0.1	29	60.9
	Medium	125	0.5	37.1	87.4
	Large	286	6.6	69.6	209.8
General cropping	Small	68	0	4	64
	Medium	88	0.1	8.7	79.2
	Large	359	3.7	23.4	331.9
Cattle and sheep (lowland)	Small	80	2	51.2	26.8
	Medium	121	0.1	78	42.9
	Large	205	5	91.4	108.6

Table 2
Yields, outputs, variable costs and gross margins of conventional crops (Source: Farm Management Handbook; SAC, 2007b).

	Winter wheat	Winter barley	Winter oats	Oilseed rape	Field beans
Yield					
Yield (grain/seed) (t/ha)	8	7.5	7.5	4	5
Yield (straw) (t/ha)	5.2	5.6	6.4		
Output					
Grain/seed (£/t)	115	105	105	185	135
Straw (£/t)	25	30	35		
Grain/seed (£/ha)	920	788	788	740	674
Straw (£/ha)	130	168	224		
Total output (£/ha)	1050	956	1012	740	674
Variable costs					
Seed (£/t)	275	270	290	7000	350
Seed (£/ha)	63	59	55	45	88
Fertiliser	143	134	98	127	31
Contract				48	48
Sprays	92	60	59	84	91
Other crop expenses	14	15	17		
Total variable costs (£/ha)	312	268	229	304	258
Gross margin	738	688	783	436	417

the prices achieved for such crops have increased considerably, the focus group participants suggested that prices offered for energy crops have failed to keep up. Prices, and input costs, for conventional activities included in the model (see Table 2) were updated using the 2007/2008 edition of the Farm Management Handbook (SAC, 2007b), and the analysis re-run to investigate the gross margins that would have to be achieved by energy crops to bring about adoption.

Prices were based on a single year rather than taking a weighted mean of prices over 5 years, as it was felt that doing so would not accurately reflect the price expectations of farmers. Among focus group participants (Sherrington et al., 2008) there was much speculation (and some excitement) as to how high the wheat price might go. UK wheat futures rose from around £90/t in January 2007 to a peak of £190/t in March 2008. While they have subsequently fallen back, the current futures price for feed wheat for delivery in November 2010 is £115/t (Farmers Weekly, 2009a), which is well above the 5 year average. Moreover, the OECD's outlook for the next decade is that agricultural commodity prices will remain at a higher level than in the past 10 years (Farmers Weekly, 2009b). Therefore, the prices used in the model, as shown in Table 3, while above the 5 year average, are well below the peaks of recent years.

Table 3
Comparison of conventional crop prices between 2002/2003 and 2007/2008 (Source: Farm Management Handbook; SAC, 2002; SAC, 2007b).

Activity	Price (£/t) 2002–2003	Price (£/t) 2007–2008
Winter wheat	70	115
Winter barley	66	105
Winter oats	56	105
Oilseed rape	144	185
Field beans	74	135

A simple budgeting analysis would suggest that new activities would have to provide gross margins greater than those for alternative crops in order to be adopted. However, agronomic and practical constraints prevent farmers from growing a single but profitable crop. Instead, crop interactions within a rotation give rise to an optimum combination of crops within a farm business. One advantage for SRC willow and miscanthus in this respect, as perennial crops, is that they fall outside of any rotational constraints.

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5. Energy crop cost, yield, and price assumptions

All periodic variable costs such as harvesting, and assumptions relating to yield, for both SRC willow (9 odt/ha/yr) and miscanthus (14 odt/ha/yr), are held at the same levels as the standard assumptions used by University of Cambridge (2005). For SRC willow at 9 odt/ha/yr the contract costs for each harvest are taken to be £311/ha. The marketing costs (for loading, weighbridge charges, and moisture testing) are £135/ha (£5/odt), and the handling & drying costs are £162/ha (£6/odt). This gives total variable costs in the harvest year of £608/ha, or approximately £203 on an annual basis.

For miscanthus, assuming yields increase up to 14 odt/ha/yr, the contract costs for each harvest are taken to be £92/ha. The marketing costs are £45/ha (£3.20/odt), and the handling and drying costs are £56/ha (£4/odt). This gives total variable costs in the harvest year of £193/ha. These cost figures, for both SRC willow and miscanthus, are consistent with those currently used by the TSEC-Biosys programme, and have been validated through discussions with industry (Bauen, 2008).

The establishment costs and associated grants, however, are updated to take account of the more recent work for Defra by Jones (2007). The ex-farm price for SRC willow has been increased to £40/odt, to represent contracts currently available to farmers in the vicinity of Drax power station (CRL, 2008). The ex-farm price for miscanthus has been increased to £60/odt, as per contracts now available to farmers wishing to supply Drax (Farmers Weekly, 2008). These costs and assumed revenues over a 16 year period are discounted at 6%, representing the farmer's cost of capital, to give a net present value (NPV) and an annual equivalent value (AEV). The AEV represents the gross margin when making the comparison with conventional annual crops.

6. Results

This section first presents the calculated likely gross margins for SRC willow and miscanthus, followed by model results showing the gross margins that would be required to achieve a certain level of uptake.

6.1. Energy crop gross margins

As with any discounted cashflow model, increased costs in the year of establishment (year 0), have a greater impact on the NPV and AEV than any increases in subsequent years. The figures presented by Jones (2007) mean that SRC willow delivers a lower gross margin under standard assumptions (see Table 4) than previously reported by University of Cambridge (2005), even when increasing the price from £35/odt to £40/odt. If the price were taken to be £44/odt, then the gross margin is £98/ha, barely changed from the University of Cambridge (2005) figure. It is of interest, however, to consider the impact of an increase in the price for SRC willow to levels suggested by Valentine et al. (2008). The authors suggest that £45–60/odt is a more realistic price in terms of the developing market. This would deliver a gross margin of between £106/ha and £221/ha. A higher potential value of £75/odt is suggested as better representing the inherent energy value. This would deliver a gross margin of £337. However, for the purposes of this exercise, the use of the £40/odt figure is justified as this represents what is currently available on a large scale contract.

Miscanthus, on the other hand, now shows a greatly increased gross margin of £444/ha based on the significant increase in price to £60/odt (see Table 5). However, it is not clear whether this price would be offered for supply to facilities other than Drax. Had the price remained at £25/odt, the effect of the revised establishment costs and grant levels would have been to reduce the gross margin to £35/ha. Working on the estimated price quoted by Nix (2007) of £35/odt, the gross margin would be £152/ha.

6.2. Model results

The figures below show the uptake for each farm type and size, for 2002/2003 prices of competing activities and for 2007/2008 prices. In general terms, the higher prices obtained for conventional crops in 2007/2008 have led to an increase in the gross margin that is required before energy crops are adopted. Once they are adopted, the models show smaller proportions of the

Table 4
Effect of revised establishment costs and grant levels on gross margin of SRC willow under standard assumptions.

		University of Cambridge (2005)	Amended establishment costs and grant level as per Jones (2007)
Price	£/odt	35	40
Yield	odt/ha/yr	9	9
Energy crop payment	£/ha	30	30
Establishment costs	£/ha	1273	1663
Establishment grant	£/ha	1000	665
Gross margin	£/ha	97	67

Table 5
Effect of revised establishment costs and grant levels on gross margin of miscanthus under standard assumptions.

		University of Cambridge (2005)	Amended establishment costs and grant level as per Jones (2007)
Price	£/odt	25	60
Yield	odt/ha/yr	14	14
Energy crop payment	£/ha	30	30
Establishment costs	£/ha	1691	2000
Establishment grant	£/ha	920	800
Gross margin	£/ha	75	444

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Table 6
Modelled aggregate uptake of energy crops over four farm types in England at different gross margins.

Type of farm	Size	Average size (ha)	Number of farms	Total area (ha)	% uptake at GM of £100/ha	Total area of energy crops (ha)	% uptake at GM of £125/ha	Total area of energy crops (ha)	% uptake at GM of £150/ha	Total area of energy crops (ha)
Cereals	Small	60	5653	339,180	–	–	48	162,806	49	166,198
	Medium	143	5045	721,435	–	–	40	288,574	61	440,075
	Large	392	4085	1,601,320	67	1,072,884	76	1,217,003	76	1,217,003
Mixed	Small	90	3015	271,350	–	–	31	84,119	31	84,119
	Medium	125	2091	261,375	–	–	–	–	–	–
	Large	286	1981	566,566	–	–	5.6	31,728	7	39,660
General cropping	Small	68	1796	122,128	48	58,621	48	58.621	54	65,949
	Medium	88	2569	226,072	–	–	24	54,257	30	67,822
	Large	359	3278	1,176,802	27	317,737	52	611,937	55	647,241
Cattle and sheep (low-land)	Small	80	7545	603,600	–	–	8	48,288	27	162,972
	Medium	121	1384	167,464	–	–	–	–	4	6,699
	Large	205	436	89,380	–	–	32	28,602	2	1,788
Total area (ha)				**6,146,672**		**1,449,242**		**2,585,935**		**2,899,525**

farm being allocated to energy crops in the 2007/2008 scenarios for a given gross margin. This is in line with the intuitive assumption that higher prices for alternative crops would increase the return required from energy crops before adoption.

As with all linear programming models, understanding the underlying assumptions is important in interpreting the results. One assumption is that the model is constrained so that farms are engaged in some farming activity. This means that the level of uptake for the 2002/2003 results is considered to be exaggerated at lower levels of gross margin, because until the gross margin reaches a certain level, the farmer may well choose simply to take the single farm payment, which is not linked to production, and undertake the minimum necessary to achieve 'Good Agricultural and Environmental Condition' (GAEC) which is a requirement for receipt of the payment (University of Cambridge, 2005). In reality, this is less likely to be the case in the 2007/2008 run of the model where high prices for conventional crops mean farmers are seeking to bring more land back into production (Farmers Weekly, 2007).

As noted by University of Cambridge (2005), uptake of energy crops in the model appears to occur at levels of gross margin lower than would be expected given the gross margins of conventional crops. With gross margins of £125/ha, most of the farm types/sizes modelled have adopted energy crops to some extent, and by £150/ha, all but one of the models have done so. This is related to the fact that the energy crop gross margins include the costs of machinery and labour as most work is undertaken through contract. In the model farms have a choice of using on-farm machinery and labour, which is effectively a fixed-cost aspect, or alternatively, once these resources are fully allocated, contractors and related machinery can be brought in, but these will represent a variable cost attributed to the specific activity, and will therefore reduce the gross margin of that particular activity. It is noticeable in this respect that larger farms generally seem to have lower thresholds for uptake. A large proportion of cereals are grown with the use of contractors on the larger farms, which reduces their gross margin accordingly and therefore reduces the level of gross margin necessary before energy crops become viable, and leads to higher uptake at lower gross margins (University of Cambridge, 2005). This reflects the reality that on farms where there is an existing labour force and sufficient machinery to undertake all tasks, energy crops are less likely to be adopted. If they were, and contractors were brought in to do the work (and focus group findings suggested that farmers would almost always want a contractor to undertake the specialised work), the fixed labour costs would still have to be paid even if staff were standing idle.

The model also shows major changes in cropping with relatively small changes in the gross margin of energy crops. Again, this is due to the underlying assumptions within the model, such that once the gross margin for energy crops is higher than alternative activities, large changes occur. In practice, this is thought unlikely to take place due to farmers' aversion to risk, which is not considered within the model (University of Cambridge, 2005).

6.3. *Aggregate levels of uptake*

It is of interest to investigate what the observed results at the farm-scale might mean in terms of production on a regional or national basis. At the simplest level, this involves aggregation of the farm-level results. However, it is important to note that when reporting farm-level results, no account is taken of longer term market conditions, and the 'small firm' case prevails where no endogenous changes in demand or supply are implemented by the model. Therefore, as supply levels shift, the resultant changes in price are not accounted for, and should be borne in mind when interpreting such aggregated estimates (Revell and Oglethorpe, 2003).

Table 6 shows the results for each of the 12 farm type and size combinations when aggregated using data on the number of such businesses in England from the June Census (Defra, 2002). These indicate that on comparison of financial returns alone, and abstracting from known barriers to adoption, the theoretical potential of 350,000 ha for the UK as a whole (Defra, 2007) should readily be achieved.

Taking the estimated price quoted by Nix (2007) for miscanthus of £35/odt to be representative of what has been available to farmers in recent years, the gross margin would typically be £152/ha. At this level, as shown in Table 6, the models show an aggregate uptake of almost 2.9 million ha, which is over

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eight times the theoretical potential as considered by Defra (2007). While this is likely to be an exaggerated level, as it does not account of any changes in price as a response to increased supply, notwithstanding the general reluctance on the part of farmers to make large changes to their cropping plan simply on the basis of a more competitive gross margin, it does demonstrate that for many farms, a crop providing these returns, using a price at the lower end of what is currently available, should be attractive. The most recent available figures on miscanthus uptake indicate an area of 12,627 ha in England (Defra, 2006), which is less than 0.5% of the modelled level.

7. Discussion

It is possible to identify from Figs. 1–4 the general trend in uptake of the energy crop option, resulting from increased prices for conventional activities. One might quite reasonably assume that taking an average of prices between 2002/2003 and 2007/2008 might generate levels of energy crop uptake that follow the same trends, but lying between the levels shown for the different years. The results of this model should not, however, be taken as a forecast for a number of reasons that have been outlined in the text. These include the novel nature of the crops, the lack of an established market, and the associated risks as perceived by farmers.

Previous research has identified that in general there tend to be fewer barriers to the adoption of miscanthus than there are for SRC willow (Sherrington et al., 2008). Even so, miscanthus is clearly not yet an attractive crop for farmers to the extent that might be expected given the current estimated level of return. This discrepancy between the modelled results and the area of land that has actually been committed to miscanthus, which is also due in part to the limited number (and distribution) of dedicated biomass and co-firing power stations, highlights the significance of these barriers and the threat that they pose to the attainment of the technical potential of perennial energy crops in the UK (Defra, 2007).

The actual supply response of UK farmers to perennial energy crops, given the current energy and agricultural policy environment, is clearly going to be different from the modelled supply response. Farmers perceive these novel crops to present a greater risk than conventional annual crops, for numerous reasons outlined above, and will not simply switch to them when the predicted gross margin is slightly higher than for an existing activity. For most farmers, there should, however, come a point when the price offered for miscanthus or SRC willow is sufficiently high to overcome these other concerns. When this occurs, in effect, payment will accurately reflect the premium for the risk that individual farmers believe they are taking. An interesting example to observe will be farmer uptake of the £60/odt contracts for miscanthus offered by Bical for supply to Drax (Farmers Weekly, 2008). Over time, increased uptake and farmers' increased familiarity with the crops should act to reduce the required risk premium.

The prices offered by these contracts have been calculated in this paper to deliver a gross margin of £444/ha. While this may well be sufficiently attractive to enough farmers for Drax's supply expectations to be realised, it would seem, from the model, that a considerable risk premium is being paid. It is therefore worth assessing the impact of current agricultural and energy policy on the perception of risks relating to these crops, the extent to which this is dealt with in contracts, and considering what approaches might serve to lower the perceived risks, and thus lessen the barriers to adoption.

7.1. Agricultural policy support for perennial energy crops

A number of grants have been available to farmers throughout the UK for the establishment of SRC willow and miscanthus with an energy end use in mind. In England, the Energy Crops Scheme (ECS) under the 2000–2006 England Rural Development

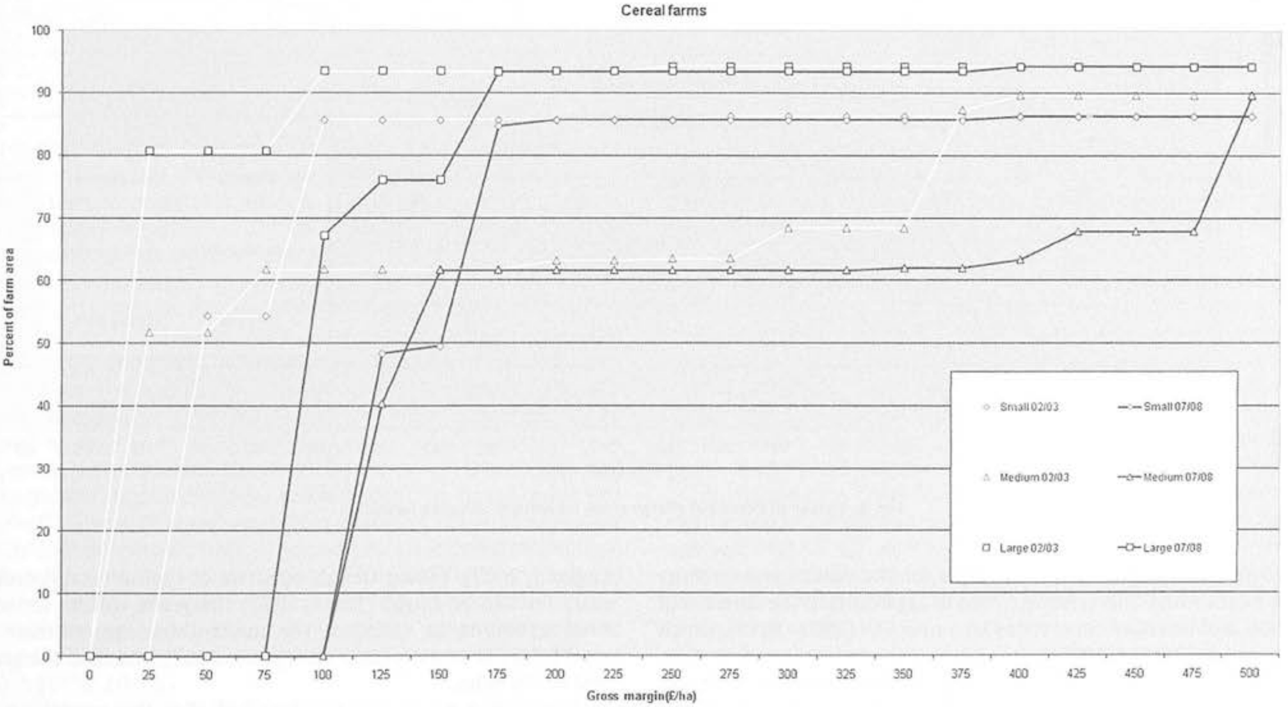

Fig. 1. Uptake of perennial energy crops on cereal farms.

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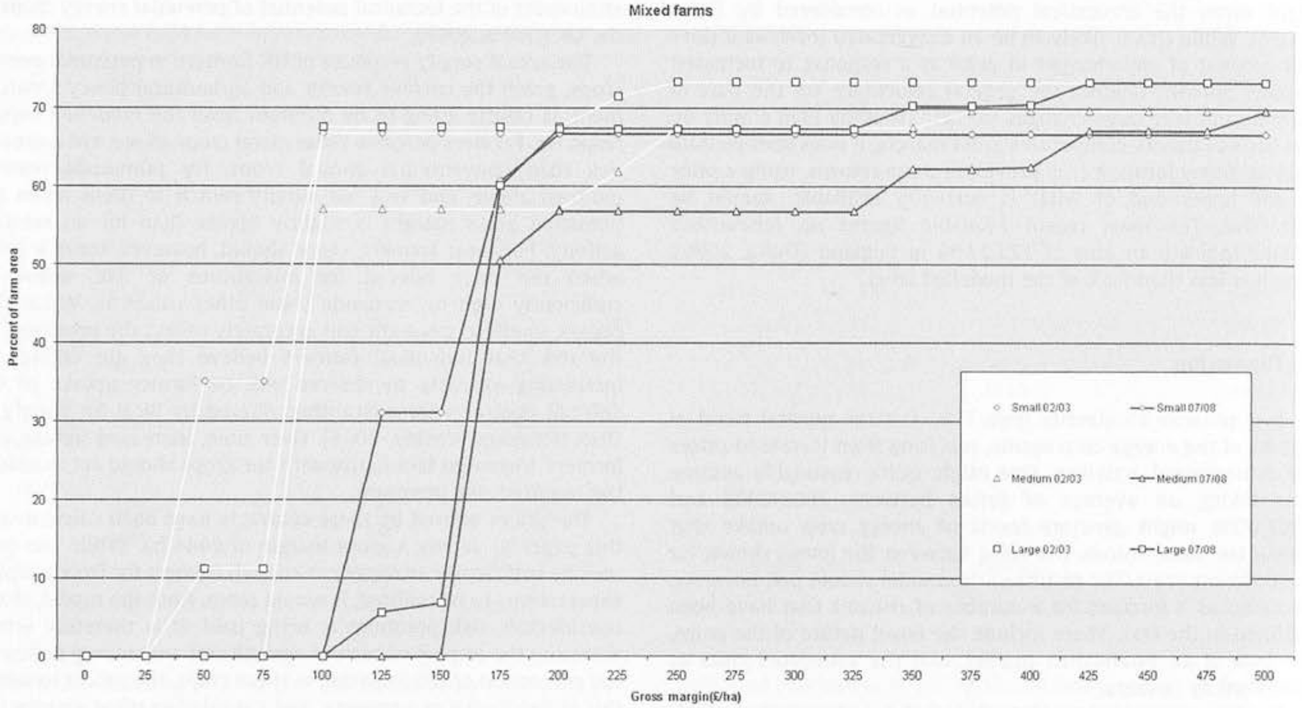

Fig. 2. Uptake of perennial energy crops on mixed farms.

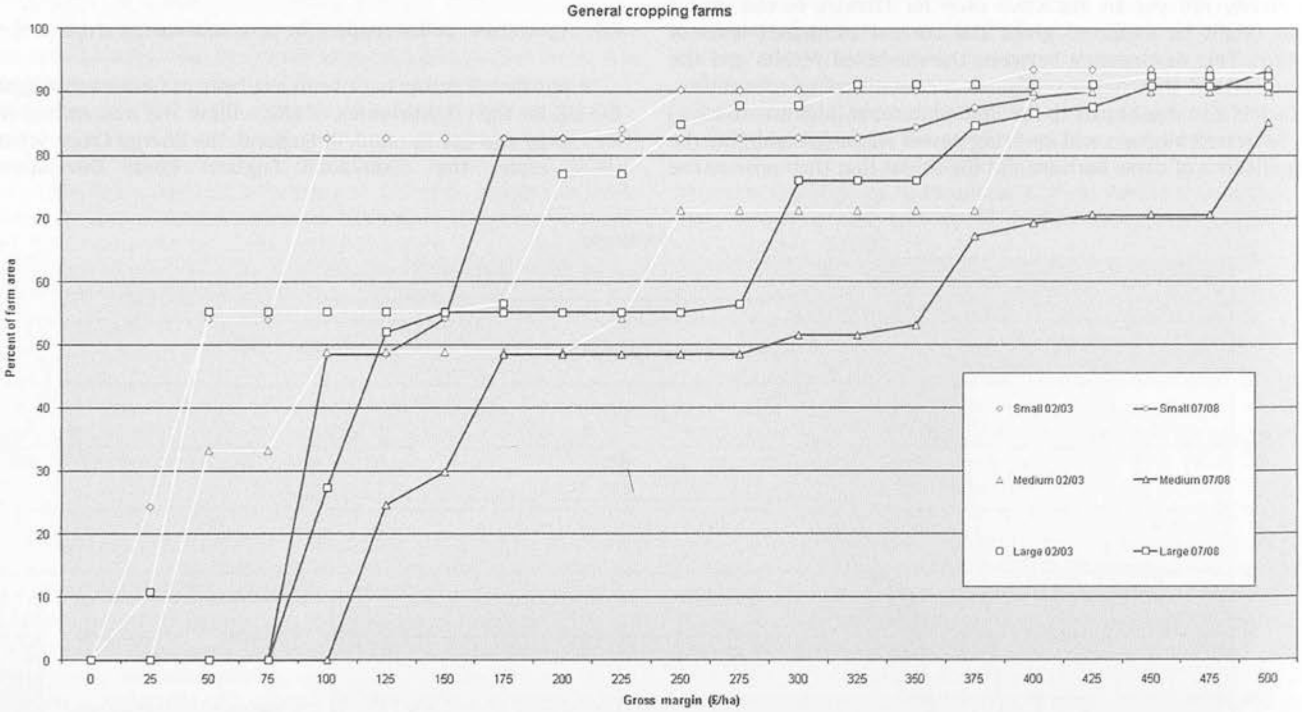

Fig. 3. Uptake of perennial energy crops on general cropping farms.

Programme (ERDP) offered £1000/ha for SRC willow and £920/ha for miscanthus. This scheme closed to applicants in the summer of 2006, and has been superseded by a new ECS (2007–2013), which opened in October 2007.

The main difference with the new scheme is that for both SRC and miscanthus, payment will be based on 40% of actual establishment costs instead of a fixed hectarage basis (Natural England, 2007). Taking Defra's estimate of typical establishment costs for SRC of £1663 (Jones, 2007) the grant will be reduced from £1000/ha to £665/ha. For miscanthus, the estimate of establishment costs is £2000/ha (Jones, 2007), and thus the grant will be £800/ha.

Sherrington et al. (2008) identified that the establishment grant is of key importance to focus group participants. Very few

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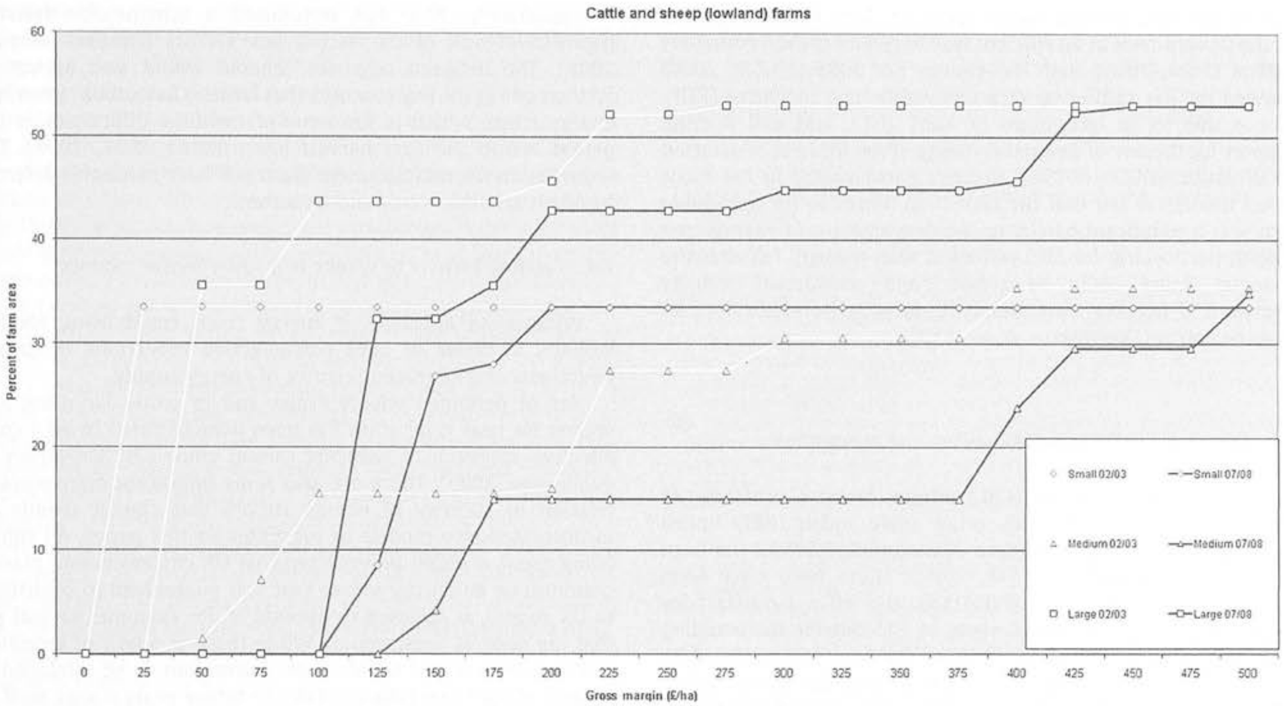

Fig. 4. Uptake of perennial energy crops on cattle and sheep (lowland) farms.

would consider growing perennial energy crops in the absence of the grant, due to high upfront costs and uncertainties over the resulting net income (Sherrington et al., 2008). While farmers still have concerns over the security of income from energy crop contracts (Sherrington et al., 2008; Sherrington and Moran, 2008), this reduction in the level of upfront support does not appear to be consistent with the aim of encouraging a wider uptake (Defra, 2007). From the perspective of farmers taking part in the focus groups, this would make the crops less attractive.

7.2. *Energy policy support for perennial energy crops*

The Renewables Obligation (RO) is the UK Government's key policy mechanism for increasing the proportion of electricity derived from renewable sources. Under the scheme there is a mandatory requirement for UK electricity suppliers to source a growing percentage of electricity from eligible renewable generation capacity.

In April 2009, the RO changed from being 'technology' neutral, awarding ROCs for every MWh of electricity produced from any eligible renewable source, to providing different levels of support to different technologies through 'banding'. Technologies are now grouped in 'bands', receiving 0.25, 0.5, 1, 1.5 or 2 ROCs per MWh, based on their level of development and generation costs. This is to encourage a greater diversity of renewable technologies and give greater support for those technologies that are currently less cost-effective. Under the amended Obligation, co-firing of regular (non-energy crop) biomass, considered an established technology, receives a reduced level of support of 0.5 ROCs, while co-firing of energy crops is awarded 1 ROC for every MWh. Dedicated regular biomass receives 1.5 ROCs, while energy crops in dedicated biomass burners or in combined heat and power (CHP) receive 2 ROCs (OPSI, 2009).

Valentine et al. (2008) calculate that this additional 0.5 ROC payment for energy crops should be worth £28.81 per odt to electricity generators. This is based on the 2007/2008 ROC buyout price of £34.30 (BWEA, 2008) and a value to generators of 1.68 MWhe/odt (assuming wood at 35% moisture and with 35% conversion efficiency) (Valentine et al., 2008). This figure does not seem to account for a typical supplier margin, with the average of industry data showing that 88% of the ROC value is actually received by generators, the remaining 12% being held by the suppliers of electricity to end consumers (Carbon Trust, 2005). However, with the current traded ROC price of approximately £53/MWh (NFPA, 2009), it could be assumed that the additional 0.5 ROCs is worth approximately £39 per odt to generators. How much of this value might then be passed through to energy crop growers is uncertain.

Sherrington and Moran (2008) conclude that while farmers in general do not consider that miscanthus or SRC willow will give a high gross margin, simply increasing the financial return from these crops without addressing the concerns relating to security of contracts and stability of income is unlikely to result in widespread uptake. However, this is precisely what has happened with banding of the Renewables Obligation, which gives electricity generation from energy crops a higher level of support than for electricity generation from regular biomass (OPSI, 2009). This support is in fact directed towards the electricity supplier rather than the farmer, but the expectation is that the higher prices should, via the generator, feed through to farmers and increase uptake (Valentine et al., 2008).

In combination with changing agricultural policy support, it can be seen that there has been a shift in emphasis away from upfront and direct funding to the farmer via establishment grants towards the 'indirect' funding of electricity generation from perennial energy crops, which should theoretically deliver increased revenues to the farmer 4 years after initial establishment of the crops. While farmers have concerns over the security of income through currently available contracts, this will serve to reduce the effectiveness of increasing the potential financial return.

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Heat generation from energy crops has long been recognised by the Government as an efficient way to reduce carbon emissions (DTI & Defra, 2006), and The Energy Act 2008 (HMSO, 2008) allowed for the setting up of a renewable heat incentive (RHI). This is due to be introduced in April 2011, and will provide support for the use of perennial energy crops for heat generation at all scales. (DECC, 2009b). Farmers participating in the focus group discussion felt that the lack of an incentive for renewable heat was a significant barrier to the development of energy crop supply, particularly for SRC willow. It was strongly felt that the financial return could be greater, and contractual security improved, if farmers were supplying local schools, hospitals or leisure centres (Sherrington et al., 2008).

7.3. Contracts available for SRC willow and miscanthus

Coppice Resources Ltd. (CRL) offered farmers contracts, in 2007, to supply Drax, with retail price index (RPI) linked payments for the harvested crop of around £37.50/odt (ex-farm at 35% moisture content) (CRL, 2007). These have since been increased to £40/odt (CRL, 2008). CRL also offer a contract for supply to the Biojoule pellet plant, at £15/odt for the standing crop, with all harvesting, handling and haulage costs covered by CRL. A further contract is available to supply the Sembcorp Wilton 10 power station on Teeside. In 2007, this offered £41.50/odt (delivered price at £35% moisture content). This has since been increased to £61/odt, but a formula is used to account for the amount of fuel needed to dry the chip down (CRL, 2008). At 35% moisture content, and using CRL's assumption of £12/odt for haulage costs, the price equates to approximately £44/odt ex-farm. As of October 2008, CRL has no growers lined up to supply SRC willow to Drax, Biojoule, or Sembcorp Wilton 10 (CRL, 2008).

Valentine et al. (2008) consider that current prices offered for SRC willow do not fully reflect the value of the crop. In their analysis they consider £45–60/odt to be a more realistic price in terms of the developing market, and £75/odt a higher potential value based on inherent energy value. The forthcoming RHI raises the likelihood that prices for SRC willow will indeed increase in future years.

Nix (2007) quotes a price range for miscanthus of £25–£45 per odt, based on information supplied by Bical, and uses £35/odt to illustrate a gross margin calculation. More recently, a price of £60/odt ex-farm has been quoted as available through Bical to supply Drax (Farmers Weekly, 2008; Farmers Guardian, 2008). This represents a substantial improvement on the previous prices available for miscanthus

It is not clear, however, that this price will become available to farmers wishing to supply facilities other than Drax. As an independent power producer operating one 4000 MW coal fired power station, they are not representative of the vertically integrated power companies that constitute the majority of the UK's electricity generation. Drax's expenditure on carbon allowances within the EU Emissions Trading Scheme increased from £11 million in the first 6 months of 2007, to £107 million in the first 6 months of 2008. This is due both to a reduction in the number of free allocations awarded to Drax under Phase II, and an increase in the cost of the allowances that must be purchased (Carbon Finance, 2008). This would have the effect of making combustion of biomass relatively more attractive due to the benefits of avoided carbon costs. While the carbon neutrality of biomass under the EU-ETS increases its attractiveness to all power producers, other generators with a less carbon intensive mix of coal, gas, and renewable generation may not be under such pressure.

Importantly, Bical has introduced a scheme for deferred payment of 43% of the first 2 year's costs (Farmers Weekly, 2008). The deferred payment scheme would also appear to address one of the key concerns that farmers have about perennial energy crops, which is the issue of cashflow difficulties in the period before the first harvest (Sherrington et al., 2008). The reduction in the establishment grant will have made this deferred payment scheme even more important.

7.4. Tackling barriers to uptake in a cost-effective manner

Widespread adoption of energy crops could bring societal benefits in terms of both cost-effective reductions in carbon emissions, and increased security of energy supply.

Use of perennial energy crops, and in particular using SRC willow for heat generation has been demonstrated to be a cost-effective approach to reducing carbon emissions (University of Cambridge, 2005). There are also some important arguments in relation to security of energy supply that cannot readily be incorporated into models as presented in this paper. All things being equal, it might be expected that UK citizens would place a premium on an energy source that was guaranteed to contribute to UK supply, as opposed to imports of, for example, natural gas that are seen as 'less secure'. While there is a lack of empirical evidence that would enable such a premium to be modelled in respect of potential future uptake, in future years it may well be that such a premium becomes apparent, to the benefit of UK growers of energy crops.

However, current farmer perception of the risk involved in growing perennial energy crops, allied with the way agricultural and energy policy is formulated threatens to either:

(a) Prevent such potentially cost-effective carbon reduction options taking place (at least on anything other than a relatively small scale); or
(b) Increase the overall cost of reducing emissions in this way. Through the approach of increasing the contract price to such a point that it provides sufficient risk compensation for individual farmers to adopt such crops, the cost-effectiveness of this measure as a way of reducing carbon emissions, decreases.

The results from the modelling show that without the barriers to adoption, farmers would adopt energy crops at a lower gross margin than they would require at present given the perception of risk that exists. This leads to inefficient outcomes at the societal level. Farmers miss out on an opportunity to diversify and establish new markets, energy suppliers (and ultimately consumers) pay higher prices than they otherwise would, and an opportunity to abate carbon at a lower cost is foregone.

There are a number of potential advantages for society as a whole that arise when risks in agriculture are shared, through routes such as insurance, marketing contracts, or external equity financing (Meuwissen et al., 2000). One key benefit is that the possibility of sharing risks permits individuals to engage in risky activities, which they would otherwise not undertake. In so doing, the expected return to society is increased over what would prevail if individual agents were constrained to accept only those risks they could afford themselves to bear (Arrow, 1992; Hardaker et al., 1997; Rejda, 1998). In addition, if farmers can trade away part of their risks so that they can move closer to the point of expected profit maximisation – but not fully because there are costs involved – the result will be a more socially desirable allocation of resources (Myers, 1998). Moreover, if farmers need to put less effort into on-farm methods of avoiding risks, they

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might well be able to use their resources more efficiently, which in turn implies greater overall efficiency in resource use (Hardaker et al., 1997; Rejda, 1998).

In the context of perennial energy crops, a form of insurance available to growers that would serve to reduce concerns about the security and stability of incomes from contracts, would have the wider societal benefit of enabling cost-effective reductions in carbon emissions, alongside the potential energy security benefits. Until the market becomes more established, there is arguably a role for Government in acting as guarantor, or at least becoming more actively involved in the provision of a form of insurance.

In tackling the known barriers to adoption in this way, the actual supply curve would move closer to the modelled supply curve. As outlined by Sherrington and Moran (2008), perception of financial return from perennial energy crops is not simply a question of anticipated gross margin. Of greater concern to farmers is the security and stability of income from contracts, disruption to cashflow, and reduced farm business flexibility. While the issue of reduced farm business flexibility is difficult to address, concerns over security and stability of income from contracts could be tackled through Government intervention to establish an insurance scheme. In addition, the design of the contracts themselves can help to reduce the disruption to cashflow. The contracts recently offered by Bical demonstrate this in offering deferred payment of 43% of the first 2 year's costs (Farmers Weekly, 2008).

Directly tackling these known barriers to adoption in this way would lead to uptake of perennial energy crops by farmers at lower gross margins, would help the market to become established, and enable the achievement of carbon reductions at a lower cost than would otherwise have been the case.

8. Conclusion

Farm-level modelling suggests that miscanthus, at current prices, should be more widely adopted than is the case. This lends support to the existence of previously identified barriers to adoption (Sherrington et al., 2008; Sherrington and Moran, 2008). SRC willow, on the other hand, remains less financially competitive at present, although the potential for higher prices for heat use is apparent.

Establishment grants are of key importance in encouraging farmers to adopt these crops, as farmers have concerns with the security and stability of income from the available contracts. However, the establishment grants for both miscanthus and SRC willow have been reduced, with greater emphasis now being placed on higher prices available to farmers through contracts. This has meant a drop in the proportion of income that is received upfront and seen by farmers to be secure, and a greater emphasis on deferred income, perceived as less secure. While increasing prices should eventually compensate for the perceived risks facing the individual farmer, this would appear to be an unnecessarily expensive approach when a large number of these risks have already been identified.

An alternative approach, outlined in this paper is for Government directly to address farmer concerns about security and stability of income from contracts through the establishment of an insurance scheme, and for the contracts themselves to be amended to allow for a smoothing of farmer cashflow. This would have the effect of bringing the actual supply response closer to the modelled supply response, and increasing the uptake among UK farmers at lower gross margins. This would allow the achievement of carbon reductions at a lower cost than would otherwise be the case.

References

ADAS, 2003. The Mid-Term Evaluation of the England Rural Development Programme (ERDP): Energy Crop Scheme. Available at 〈http://www.defra.gov.uk/erdp/pdfs/midterm/cs_ecs_3.pdf〉 (accessed August 2007).

Arrow, K.J., 1992. Insurance, risk and resource allocation. In: Dionne, G., Harrington, S.E. (Eds.), Foundations of Insurance Economics. Readings in Economics and Finance. Heubner International Series on Risk, Insurance and Economic Security. Kluwer Academic Publishers Group, Dordrecht, pp. 220–229.

Bauen, A. 2008. Personal communication, 16 December 2008.

BWEA, 2008. The Renewables Obligation page on the British Wind Energy Association website 〈www.bwea.com/business/roc.htm〉.

Carbon Finance, 2008. EU-ETS Prices bite into Drax's profits. Europe News, 6 August 2008. Available at 〈http://www.carbon-financeonline.com/index.cfm?section=europe&action=view&id=11433〉 (accessed August 2008).

Carbon Trust, 2005. Biomass sector review for the Carbon Trust, October 2005. Available at 〈http://www.carbontrust.co.uk/publications/publicationdetail?productid=CTC512〉 (accessed July 2007).

CRL, 2007. Personal communication with Barbara Hilton of Coppice Resources Ltd., August 2007.

CRL, 2008. Personal communication with Barbara Hilton of Coppice Resources Ltd., October 2008.

DARDNI, 2007. Renewable Energy Action Plan, Department of Agriculture and Rural Development Northern Ireland, January 2007. Available at 〈http://www.dardni.gov.uk/renewable-energy-action-plan-2.pdf〉 (accessed July 2007).

DECC, 2009a. The UK Renewable Energy Strategy. Department of Energy & Climate Change, July 2009.

DECC, 2009b. Renewable Heat Incentive webpage. Available at 〈http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/policy/renewable_heat/incentive/incentive.aspx〉 (accessed November 2009).

Defra, 2002. Farm Business Survey 2001/2002, sample characteristics. Farm Accounts in England 2002/2003.

Defra, 2006. Creating value from renewable materials: a strategy for non-food crops and uses—two year progress report. Department for Environment, Food and Rural Affairs, November 2006. Available at 〈http://www.defra.gov.uk/farm/crops/industrial/pdf/nfc-progress-0611.pdf〉 (accessed July 2007).

Defra, 2007. UK Biomass Strategy. Department for Environment, Food and Rural Affairs, May 2007.

DTI, 2003. Renewables Innovation Review. Department of Trade and Industry. Available at 〈http://www.dti.gov.uk/files/file22017.pdf〉 (accessed July 2007).

DTI & Defra, 2006. The Government's response to the Biomass Task Force Report. Available at 〈http://www.berr.gov.uk/files/file28197.pdf〉 (accessed November 2009).

E4Tech, 2009. Biomass Supply Curves for the UK, March 2009. Available at 〈http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/res/res.aspx〉 (accessed November 2009).

European Parliament and Council of the European Union, 2009. Directive of the European Parliament and of the Council on the Promotion of the Use of Energy from Renewable Source. PE-CONS 3736/08, Brussels, 26 March 2009. Available at 〈http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF〉(accessed May 2009).

Farmers Guardian, 2008. Renewable energy strategy makes miscanthus 'an attractive alternative', August 15 2008. Available at 〈http://www.farmersguardian.com/story.asp?sectioncode=19&storycode=20678〉 (accessed August 2008).

Farmers Weekly, 2007. NFU President explains why farmers should welcome the end of set-aside. Available at 〈http://www.fwi.co.uk/Articles/2007/09/27/107146/nfu-president-explains-why-uk-farmers-should-welcome-an-end-to-set-aside.html〉 (accessed September 2008).

Farmers Weekly, 2008. Biofuels brief: huge growth for UK biomass, September 3 2008. Available at 〈http://www.fwi.co.uk/Articles/2008/09/03/111947/biofuels-brief-huge-growth-for-uk-biomass.html〉 (accessed September 2008).

Farmers Weekly, 2009a. Liffe prices—wheat futures prices for 19 November 2009. Available at 〈http://www.fwi.co.uk/StaticPages/liffeprices.htm〉 (accessed November 2009).

Farmers Weekly, 2009b. Long-term view suggests higher world commodity prices. Available at 〈http://www.fwi.co.uk/Articles/2009/01/07/113704/long-term-view-suggests-higher-world-commodity-prices.html〉 (accessed January 2009).

FAO, 2007. Crop Prospects and Food Situation, No. 5. Food and Agriculture Organisation of the United Nations, Rome, October 2007.

Hardaker, J.B., Huirne, R.B.M., Anderson, J.R., 1997. Coping with Risk in Agriculture. CAB International, Wallingford.

HMSO (2008) Energy Act 2008. Her Majesty's Stationery Office, London, 26 November 2008. Available at 〈http://www.opsi.gov.uk/acts/acts2008/pdf/ukpga_20080032_en.pdf〉(accessed May 2009).

Jones, J., 2007. Verification of the calculations, methodology and costings used in determining proposed establishment grant payments under the Energy Crops Scheme—a report for Defra, May 2007.

Meijer, I.S.M., Hekkert, M.P., Koppenjan, J.F.M., 2007. The influence of perceived uncertainty on entrepreneurial action in emerging renewable energy technology; biomass gasification projects in the Netherlands. Energy Policy 35, 5836–5854.

Please cite this article as: Sherrington, C., Moran, D., Modelling farmer uptake of perennial energy crops in the UK. Energy Policy (2010), doi:10.1016/j.enpol.2010.02.034

Meuwissen, M.P.M., Hardaker, J.B., Huirne, R.B.M., Dijkhuizen, A.A., 2000. Sharing risks in agriculture; principles and empirical results. Netherlands Journal of Agricultural Science 49 (2001), 343–356.

Myers, R.J., 1998. The value of ideal contingency markets in agriculture. American Journal of Agricultural Economics 70, 233–242.

Natural England, 2007. Confirmation of the details of the Energy Crops Scheme—information for applicants. Available at 〈http://www.naturalengland.org.uk/planning/grants-funding/energy-crops/docs/ecs-confirmation.pdf〉 (accessed August 2008).

NFPA, 2009. ROC auction prices page on Non Fossil Purchasing Agency website 〈http://www.nfpa.co.uk〉 (accessed August 2009).

Nix, 2007. Farm Management Pocketbook 38th edition Imperial College London, Wye Campus 2008.

OPSI, 2009. The Renewables Obligation Order 2009. Office of Public Sector Information. Available at 〈http://www.england-legislation.hmso.gov.uk/si/si2009/uksi_20090785_en_1〉 (accessed November 2009).

Rejda, G.E., 1998. Principles of Risk Management and Insurance. Harper Collins, New York.

RELU, 2009. Policy and Practice Note No. 9, Assessing the social, environmental and economic impacts of increasing rural land use under energy crops. Rural Economy and Land Use Programme, September 2009. Available at 〈http://www.relu.ac.uk/news/policy%20and%20practice%20notes/Karp/Karp.pdf〉 (accessed November 2009).

Revell, B. and Oglethorpe, D., 2003. Decoupling and UK agriculture: a whole farm approach. An appraisal of the impact on the livestock sector, commissioned by Defra.

RCEP, 2004. Biomass as a renewable energy source: a limited report by the Royal Commission on Environmental Pollution.

SAC, 2002. Farm Management Handbook 2002/2003. Scottish Agricultural College.

SAC, 2007a. Commercial viability of alternative non food crops and biomass on Scottish Farms—a special study supported under SEERAD Advisory Activity 211, March 2007. Available at 〈http://www.sac.ac.uk/mainrep/pdfs/nonfoodbiomass.pdf〉 (accessed July 2007).

SAC, 2007b. Farm Management Handbook 2007/2008. Scottish Agricultural College.

Sherrington, C., Bartley, J., Moran, D., 2008. Farm-level constraints on the domestic supply of perennial energy crops in the UK. Energy Policy 36, 2504–2512.

Sherrington, C. and Moran, D., 2008. Farmer attitudes and intentions towards the adoption of perennial energy crops in the UK: an application of the Theory of Planned Behaviour. Paper presented at the 16th European Biomass Conference & Exhibition, From Research to Industry & Markets, Feria Valencia, Spain, 2–6 June 2008.

University of Cambridge, 2005. Farm level economic impacts of energy crop production. Final Report to Defra, August 2005.

Valentine, J., Heaton, R., Randerson, P. and Duller, C., 2008. The economics of short-rotation coppice willow in the UK. Paper presented at the 16th European Biomass Conference & Exhibition, From Research to Industry & Markets, Feria Valencia, Spain, 2–6 June 2008.

Welsh Assembly Government, 2007. Personal communication from Vicky Davies, Rural Development Adviser. Technical Services Division. Welsh Assembly Government, Llandrindod Wells.

Please cite this article as: Sherrington, C., Moran, D., Modelling farmer uptake of perennial energy crops in the UK. Energy Policy (2010), doi:10.1016/j.enpol.2010.02.034

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An economic assessment of windfarm power generation in Scotland including externalities

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Abstract

This paper uses cost–benefit analysis to assess the economic feasibility of a large scale windfarm project, taking into account positive and negative externalities of generation. The issue of non-use value (i.e. a welfare change among those who will never visit the area and see the windfarm) is addressed with reference to the study by Bergmann et al. [2006. Valuing the attributes of renewable energy investments. Energy Policy 34, 1004–1014], which determined a social cost of £19.40 per household for the non-use disamenity associated with a large scale windfarm in Scotland. This paper demonstrates the extent to which this estimate affects the economic feasibility of the project. We find that for all but one of the 16 scenarios considered, the project returns a positive net present value despite the inclusion of this non-use value, thus suggesting that in these cases the windfarm delivers a net welfare gain to society.

Keywords: Wind energy; Externalities; Environmental valuation

1. Introduction

The projected increase in renewable generation capacity in Scotland raises a number of questions about the economic feasibility of renewable energy supplies. In addressing a global external cost, that of climate change, the development of renewables can give rise to other social costs that are predominantly domestic. Considering the full economic costs, some technologies (e.g. onshore wind power) may be less favoured since they give rise to visual disamenity that some communities feel disproportionately affected by Simpson (2004). In Scotland, there is an ongoing public debate on the issue of the visual impact of windfarms on the landscape. However, apart from Kennedy (2005), addressing offshore installations on the US eastern sea board, there has so far been no assessment of how such social costs may affect the economic feasibility of specific wind energy projects.

Accordingly, this paper presents the results of an economic cost–benefit analysis (CBA) of a large scale onshore wind energy project in southern Scotland. The aim is to consider the widest social perspective on the project taking both positive and negative externalities into account. The paper is structured as follows. First, we provide some background to the energy strategy in Scotland: a country well positioned to make greater use of renewable energy sources and currently undergoing change in its electricity generation mix. This section will also consider current hurdles to the development of renewable energy projects. Next, the project case study is introduced as a basis for quantifying the range of relevant costs and benefits and assumptions for an economic appraisal. The paper then presents the results of a formal appraisal and sensitivity analysis. The final sections offer discussion and conclusions on research gaps hindering the further development of wind capacity in Scotland and the UK.

1.1. The changing patterns of electricity generation in Scotland

While overall UK energy policy is still reserved to Westminster, following devolution in 1999, substantial

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areas relating to energy policy are now devolved to the Scottish Executive. These include the promotion of renewable energy and energy efficiency, consents for new electricity generating plant and transmission lines, and land-use planning (Scottish Executive, 2006a). Under Section 36 of the Electricity Act 1989 applications to build onshore windfarms with an installed capacity in excess of 50 MW are made to Scottish Ministers. Below this size, applications are made to the local planning authority, and considered under the Town and Country Planning (Scotland) Act 1997.

This new responsibility comes at a time when the electricity supply industry in Scotland is set, over the next 10–20 years, to undergo a period of rapid transformation. This change is being driven by a range of internal and external factors (see Macleod et al., 2006). An outcome of this transition is a move towards an energy mix that gives greater weight to renewables. The Scottish Executive has set two targets for use of renewable power sources. By 2010, 18% of electricity consumed should come from renewable generation, rising to 40% by 2020 (Scottish Executive, 2003). In 2005, the Scottish Ministers reconfirmed the 2020 target, quantifying it as 6 GW (Gigawatts) of installed renewables capacity, confirming that this figure should not be regarded as a cap on development (Scottish Executive, 2005).

A study by Scottish Renewables indicates that by April 2006, 2 GW of installed renewable capacity was operating in Scotland. Across 12 months, this capacity should generate around 18% of the anticipated Scottish demand for electricity, thus meeting the 2010 target three years ahead of schedule. The study anticipates that by 2010 over 30% of Scotland's electricity could come from renewables, and over half by 2020 (Scottish Renewables, 2006). Onshore wind is expected to play a significant role, with a predicted 2.7 GW installed capacity generating 20% of Scotland's demand for electricity in 2010, and 4.2 GW installed capacity generating 29% in 2020.

Environmental and economic benefits and costs will accrue to Scotland as a result of these increases in the capacity of onshore wind.

1.2. Possible problems with wind energy

Several arguments are used to oppose windfarms. A commonly cited concern relates to the potential "intermittency" or more accurately the variability of electricity supply from wind power (ECI, 2005), and the requirement for back up generation capacity. All generators including fossil fuel and nuclear plant need back up, and it is not the case that a dedicated plant would have to be constructed to be held in reserve for windfarms. In Scotland, when production from dispatchable balancing plant is required to make up for an anticipated shortfall in supply, there are a number of options available. These include approximately 1.3 GW of hydro-electric plant, 700 MW of pumped storage, and 500 MW from fast-starting generators and interconnections to England and Northern Ireland (Scottish Executive, 2006b).

A further concern is the potential for intrusive noise both during construction and operation of the windfarm, although recent advances in turbine design have reduced both mechanical and aerodynamic noise. However, the key motivation for anti-windfarm campaigners is opposition to the visual despoliation of valued landscapes (Pasqualetti et al., 2002; Burall, 2004). The landscape impacts are exacerbated by the fact that the locations with the highest wind resource are often precisely those exposed upland areas which are valued for their scenic qualities and which are often ecologically sensitive. Opponents not only highlight the scenic impact of the turbines themselves, but also emphasize the visual impacts of the associated construction and upgrades to the electricity transmission system (Warren et al., 2005).

This disquiet about the installation of wind capacity is often expressed in a somewhat unspecific way, combining elements of both use value (residents and visitors who will see—and possibly hear—the windfarm) and non-use value (those who may never visit the area and see the windfarm). In other words, some altered landscapes may affect people's welfare because their use experience is tarnished. For others, the option to visit a landscape free of turbines, or simply the knowledge that a "pristine" landscape exists is a primary reason for valuing the status quo.

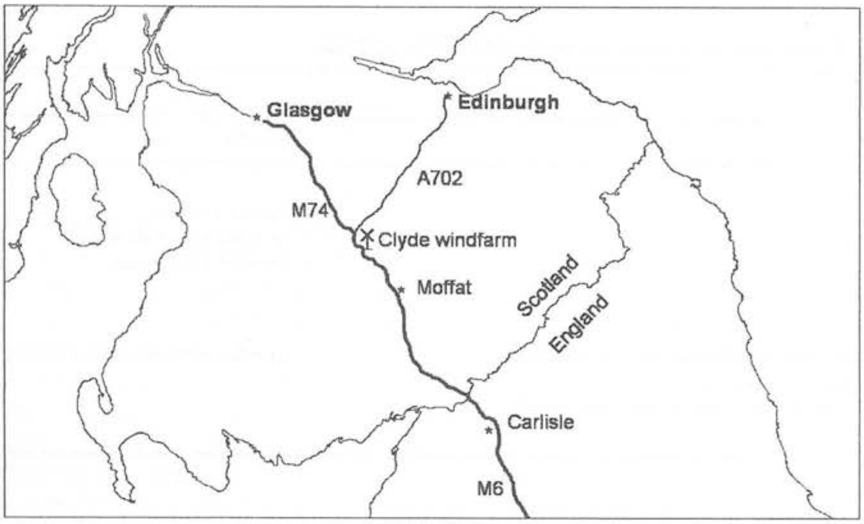
While it is technically possible to quantify these views, there is limited empirical evidence. A study of public perceptions of wind power in Scotland and Ireland suggested an "inverse NIMBY" syndrome, where those with windfarms in their "backyard" strongly support the technology (Warren et al., 2005). But a study on non-use value impacts suggests that a large (160 MW) onshore windfarm with a considerable landscape impact, results in a welfare loss of £19.40 per household per year (Bergmann et al., 2006). The details and application of this value are discussed later in this study.

1.3. The project

The case study is a proposed windfarm is located in the Upper Clyde Valley in South Lanarkshire, Scotland. The scheme proposes the installation of 173 wind turbines each with a generating capacity of 3.6 MW, a hub height of 80 m and a blade diameter of 90 m (total height 125 m). It is proposed that one of the turbines will have a viewing platform. Taking three years to construct, the project is designed with an operational life of 25 years (Map 1).

With a total installed capacity of just over 620 MW, the developers suggest that the site will generate enough electricity to power up to 440,000 households, and will contribute 0.5% towards the Government's target of 10% of the UK's energy coming from renewable sources by 2010.

The site is divided by the M74 motorway running between Abington, Elvanfoot and Crawford. It occupies



Map 1. Location of the proposed Clyde windfarm (® Ordnance Survey).

approximately 4750 ha (hectares) of farmland, consisting mainly of permanent grassland currently used for sheep grazing, and areas of commercial forestry and heathland.

2. Social cost–benefit analysis (CBA)

While it is possible to adopt a private perspective on this project, the presence of wider external costs and the level of public disquiet suggest a more stringent test of economic viability. Social CBA offers a consistent analytical framework for decision-making and is typically designed to help decision-makers allocate scarce resources by determining which option among a competing set should be selected in order to maximize social welfare. This welfare objective encompasses measurable monetary benefits as well as more intangible non-market benefits or public good externalities. Social CBA is typically the perspective adopted by government, and standard guidance is provided by the UK Treasury.[1]

The CBA requires the identification of a baseline or status quo scenario, against which the costs and benefits of alternative project interventions are evaluated. The central counterfactual for our analysis below is a gas-fired plant of equivalent generating capacity, although the counterfactual of a coal-fired plant is also considered.

For the Clyde Valley proposal, the relevant cost and benefit categories to be considered are identified in Table 1.

The installed capacity of the Clyde windfarm is taken to be 622.8 MW (based on 173 turbines each rated at 3.6 MW) as outlined in the Environmental Statement (Land Use Consultants, 2004). Airtricity expects that the Clyde windfarm will have a capacity factor of 38%, that is, the site will operate at the equivalent of full power 38% of the time. The counterfactual gas-fired power station, assuming an availability factor of 67% (DTI, 2005), has a capacity of 353 MW. The counterfactual coal-fired power station, assuming an availability factor of 57.9% (DTI, 2005), has a capacity of 409 MW.

Relevant costs and benefits are considered over a time horizon of 25 years. The Treasury *social discount rate* is currently 3.5%. However, the analysis makes a case for alternative discounting assumptions

2.1. Market costs

2.1.1. Capital investment

The capital cost of the Clyde windfarm is £405 million over a three year period. This is based on a cost of £0.65 million per installed MW for onshore wind (Dale et al., 2004). The value used in the CBA is the difference between this and the cost of constructing an equivalent 353 MW gas-fired power station of £159 million, taking the cost per installed MW for gas to be £0.45 million (Dale et al., 2004) The difference in cost between the two is £246 million, which will be the construction cost figure, where gas is the counterfactual, in the analysis to follow.

The 409 MW coal-fired power station has a construction cost of £335 million, based on a cost of £0.82 million per MW (Royal Academy of Engineering, 2004). Subtracting from the capital cost of the Clyde windfarm gives a construction cost of £70 million, which will be the figure used, where coal is the counterfactual, in the analysis to follow.

Construction takes three years, and a third of the total cost of construction is attributed to each year. One third of the windfarm will be operational for the second year, and two-thirds for the third year.

2.1.2. Operation and maintenance (O&M)

Annual O&M costs are £9.3 million. This is based on an O&M cost for onshore wind of £15/(kW y) (Dale et al.,

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[1] http://www.hm-treasury.gov.uk/economic_data_and_tools/greenbook/data_greenbook_index.cfm.

Table 1
The categories of costs and benefits to be used in the assessment of the Clyde windfarm

Costs and benefits of wind energy	
Costs	Benefits
Market	
Capital investment	Output revenues
Operation and maintenance	Avoided fuel costs (gas)
Extra balancing costs to the grid	Avoided GDP losses
Rental cost of land	
Non-market	
Carbon dioxide emissions through manufacture and construction	Avoided emission costs associated with displaced generation
Carbon dioxide emissions through deforestation	
Visual and noise disamenity for residents and visitors (use value)	
Non-use disamenity value	

2004). The value used in the CBA is the difference between this and the annual O&M cost of the equivalent 353 MW gas-fired power station, taken to be £7 million, based on a figure of £20/(kW y) (Dale et al., 2004).[2] Subtracting the gas-fired equivalent O&M costs from the Clyde windfarm O&M costs gives a net annual O&M figure of £2.3 million, to be used where gas is the counterfactual, in the analysis to follow.

For the equivalent 409 MW coal-fired power station, the annual O&M cost is £9.8 million, based on a cost of £24/(kW y) (Royal Academy of Engineering, 2004). Subtracting the coal-fired equivalent O&M cost from the Clyde windfarm O&M cost gives a net annual O&M figure of −£0.4 million, to be used where coal is the counterfactual in the analysis to follow.

For the second year of construction, one-third of the windfarm is taken to be operational, with two-thirds operational for the third year. The net O&M costs for these years are calculated as above, but adjusted to reflect the installed and operational capacity in the second and third years of construction. Therefore the O&M costs, for gas as the counterfactual, are taken to be £0.75 million (a third of the net annual O&M cost of £2.3 million) in the second year of construction, and £1.5 million (two-thirds of £2.3 million) in the third year of construction. O&M costs where coal is the counterfactual are calculated in the same way for these years.

The analysis is simplified by the assumption that the counterfactual generating plant is brought online in stages comparable to that of the windfarm. This is due to the assumption that equivalent revenue from generation (excluding ROCs) is received by the windfarm and the counterfactuals (see Section 2.2.1) throughout each year of their operational life. In reality, a combined cycle gas turbine (CCGT) plant may be fully operational after two years construction, meaning that at the end of the windfarm's three years construction period, an equal amount of electricity will, in fact, have been generated from both the windfarm and the counterfactual. This would mean that revenue will have been earned from the windfarm one year earlier, but O&M costs will also have been paid earlier. A comparison has demonstrated that altering this simplifying assumption would only make a difference of between 0.03% and 0.12% to the NPV (prior to the application of the non-use value), and therefore the assumption remains.

2.1.3. *Extra balancing costs to the grid*

As the amount of wind generation on the electricity network increases, and the uncertainties in wind output start to become evident above the normal level of uncertainty in balancing supply and demand, some extra balancing costs will be incurred (Dale et al., 2004).

The estimates to be used in this study are those resulting from the SCAR study (Ilex Energy Consulting and Strbac, 2002). These show that the extra balancing costs for wind are 0.1 p/kW h at 5.3% penetration, 0.14 p/kW h at 7.6%, 0.16 p/kW h at 10%, and 0.17 p/kW h at 14.2%. A comparison with other estimates featured in The Carbon Trust/DTI's Intermittency Literature Survey & Roadmap (Mott MacDonald, 2003) shows that these values represent the median estimate of balancing costs.

Taking the baseline scenario assumptions as applied in the DTI's Renewables Market Modelling (Oxera, 2004), we obtained the predicted level of wind penetration for each year of the Clyde windfarm's operation. We then applied a figure for the balancing cost for each year based on this forecast. These costs increase from £1.6 million for the first full year of operation to £3.5 million for the 25th year.

2.1.4. *Rental cost of land*

The annual cost to Airtricity of the rent paid to landowners at the Clyde site is £1.7 million.

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[2] The O&M figures from Dale et al. (2004) have been used in preference to those cited in the UK Energy Review (DTI, 2006, p. 194, Table B1) which give £44.4/(kW y) for wind. The Dale et al. (2004) figures are consistent with others, such as Milborrow (2005).

2.2. Market benefits

2.2.1. Output revenues

From information given by Airtricity, it has been assumed that the output revenues are 5.5 p/kW h, excluding the income from Renewables Obligation Certificates (ROCs). However, as the counterfactual investment scenario would also receive similar output revenue, this benefit stream arising from the windfarm will not be included in the analysis. If the project were to be assessed against a "do nothing" baseline, this would be included as a benefit.

The income from ROCs should not be counted in an economic analysis. ROCs arise from a support mechanism, the Renewables Obligation, designed in part to address the externality of greenhouse gas emissions from conventional fossil fuel generation, but this does not mean that their price accurately reflects the cost of this externality.

The cost of abating a tonne of carbon through the Renewables Obligation is calculated to be in the range of £212–£447 (Ofgem, 2004). This is significantly higher than the Treasury's social cost of carbon, which will be used in the analysis below. The figure used by the Treasury is £70 per tonne of carbon (in 2000 prices) as an "illustrative point estimate" of relevant damages, with an upper value of £140 and a lower value of £35 (Treasury, 2002).

2.2.2. Fuel costs avoided

This is taken to be the cost of gas used for generating electricity in the counterfactual investment scenario, including the gas transportation costs for delivery to the power station. Taking a figure of 35 p/therm (pence per therm) as the forecast price to be paid by the electricity generators for gas (ILEX, 2006), this translates to a fuel cost (assuming 50% thermal efficiency) of 2.06 p/kW h.

Recent wholesale gas prices have, however, been around 80 p/therm, equating to a cost of 4.7 p/kW h. For sensitivity, analysis will be undertaken using the gas price range applied in the UK Government's Energy Review, namely from 21 to 53 p/therm (DTI, 2006).

The calculation of avoided fuel costs takes account of anticipated seasonal variations in the load factor of the Clyde windfarm, based on average data from existing windfarms in Ireland with an equivalent load factor (38%), supplied by Airtricity. Greater load factors are achieved during the windier winter months, coinciding with periods when gas prices are typically higher than average. Monthly gas price projections (Ilex, 2005) show a circa 5 pence range in price over the year when the mean price is 35 p/therm. Converting this to an approximate percentage change from the mean per month enabled the calculation of monthly prices. Multiplying these monthly prices by the monthly load factor increases the annual avoided cost of gas by 2.6% compared with using one price and the average annual load factor. The resulting avoided fuel costs for each year of full operation of the windfarm are £43.8 million.

Fuel is a high risk cost stream, not simply because of the fluctuation in fuel prices over time, but because the cost of fuel co-varies negatively with returns on other assets; i.e. when fuel prices increase, returns to other assets decline (Awerbuch, 1995). This risk differential motivates arguments for an alternative discounting approach to these streams. In this case a rate is therefore applied to the avoided fuel cost stream using the Capital Asset Pricing Model (CAPM) approach (Awerbuch, 2003). This takes into account the extent to which the fuel cost stream co-varies systematically with the returns that would be obtained on a broadly diversified portfolio of assets.

The mathematical measure of systematic risk, β (beta), is the expected percentage variation in the cost stream when returns to a broadly diversified portfolio change by 1%. A beta of -0.02 for gas is used by Awerbuch (2006) to estimate a market (pre-tax) discount rate of 4.3% for gas. By netting out personal and corporate taxes, Awerbuch derives a Social Rate of Time Preference (SRTP) value of 1.7% nominal. Assuming a 3% rate of inflation, this gives a real discount rate of -1.1% to be applied to this cost stream.

For the coal-fired counterfactual, the cost of coal is taken to be £30/tonne, which gives a fuel cost of 1.16 p/kW h (Royal Academy of Engineering, 2004). Using the CAPM approach, a real discount rate of -1.3% is applied to this cost stream.

2.2.3. Avoided GDP losses

There is empirical evidence from a growing body of academic literature that oil price increases and volatility dampen macroeconomic growth by raising inflation and unemployment and by depressing the value of financial and other assets. These losses are in the order of 0.5% of GDP for a 10% oil price increase (Awerbuch and Sauter, 2005, Awerbuch, 2005). By displacing gas and oil, increased use of renewable energy can help nations avoid these macroeconomic losses. This avoided GDP loss is an attributable to renewable energy investments.

It is estimated that this benefit is worth $200/kW (£114/kW) for wind energy installations, based on a capacity factor of 23% (Awerbuch and Sauter, 2005, Awerbuch, 2005). For the purposes of this report, this figure has been increased to represent the 38% capacity factor of the Clyde project, giving £188/kW, and multiplied by the installed capacity (622.8 MW) to give a figure of £117.2 million. This is a one-off benefit, attributed to 2009, the first full year of the windfarm's operation.

2.3. Non-market benefits

2.3.1. Carbon emissions avoided

Electricity generated by wind power avoids emissions of carbon dioxide through the displacement of conventional fossil-fuelled generation. To quantify this benefit, it is necessary to estimate avoided emissions. This depends on the amount of electricity produced and electricity generating technology displaced. A monetary value can then be placed on these avoided costs using a shadow value of carbon.

Amount of electricity produced by the Clyde windfarm: Airtricity expect that the Clyde windfarm will have a capacity factor of 38%, that is, the site will operate at the equivalent of full power 38% of the time.

The amount of electricity produced by the windfarm can be estimated by

$$\text{Installed capacity } (M) \times \text{capacity factor} \times \text{the number of hours in a year.}$$

Therefore

$$\text{Electricity produced} = 622.8\ \text{MW} \times 0.38 \times 8760.$$

This gives 2073 GW h.

Generating sources displaced: In Scotland the immediate effect of a windfarm may be to displace the generation of electricity from hydropower. Scotland has approximately 1.3 GW of hydro-electric plant and 700 MW of pumped storage (Scottish Executive, 2006b), and in an average year, hydro generates 12% of Scotland's electricity needs (Scottish Renewables, 2006). However, the displaced hydro may then displace coal or gas generation at a later date. It is therefore assumed that wind displaces fossil fuel, either immediately or via hydro. The three options to be considered for the generation sources displaced by the Clyde windfarm in this analysis are now discussed.

Option 1—Wind displaces coal-fired generation: It is argued by the British Wind Energy Association (BWEA), that in both the short and long term, wind saves on emissions from modern coal-fired plant (BWEA, 2005). This is demonstrated in data published by The National Grid Company which describes the make-up of plant on the system at various times (National Grid Transco, 2004). The nuclear and CCGT plant operates continuously throughout the day and the output of the coal plant is varied to meet demand. It is noted that the output from coal plant will not change in response to every fluctuation in wind output. It will be adjusted in response to the aggregated change in demand, of which wind contributes only a small proportion.

In the longer term, as the older coal plants become uneconomic, or surplus to requirements due to the construction of new gas or renewables, they are shut down.

Average emissions from coal-fired plant are taken to be 0.86 kg CO_2/kW h, thus this is the CO_2 saving associated with the generation of electricity from wind if it displaces coal.

Option 2—Wind displaces the typical grid mix: The carbon intensity of the grid, based on the average grid mix is 0.43 kg CO_2/kW h (Carbon Trust, 2006). This emissions figure is taken from Defra's "Environmental Reporting Guidelines for Company Reporting on Greenhouse Gas Emissions", and is used for the purposes of environmental reporting, the UK Emissions Trading Scheme, and the Climate Change Levy agreements.

This figure for electricity was calculated in 1999 based on the projected fuel mix for the grid 1998–2000. Actual figures may differ from the projections, but it is intended to be used by Defra as a constant value for environmental reporting until the year 2010 (Defra, 2006).

It is argued that this figure does not reflect reality, suggesting as it does that wind will displace coal, gas and nuclear in equal measure. Nuclear, for example, being baseload plant, and is completely unaffected in its daily operations by the addition of new generating plant (BWEA, 2005).

Option 3—Wind displaces gas: In its Regulatory Impact Assessment for the Renewables Obligation, the DTI assumed that the main impact of extra renewables is to reduce investment in new gas combined cycle stations and that each TW h would produce 2.5 mtC. This is equivalent to a figure of 0.38 kg CO_2/kW h (DTI, 2002).

This contradicts an earlier DTI study, which states that renewables displacing CCGTs "is unlikely in practice at present, because this high efficiency (where efficiency refers to the amount of electricity generated per unit of CO_2 emitted), fossil fuel technology is being increasingly deployed in the UK" (DTI, 1999).

The assumption that wind displaces gas is supported by the Royal Academy of Engineering (2004) with open-cycle gas turbines (OCGT) identified as the most appropriate technology if talking about new build rather than just using existing plant. It is also the assumption made by Dale et al. (2004).

Carbon dioxide emissions avoided under the three scenarios:

Option 1—displacing coal	1.8 million tonnes CO_2
Option 2—displacing typical grid mix	0.9 million tonnes CO_2
Option 3—displacing gas	0.8 million tonnes CO_2

Of these, wind displacing gas will be the central assumption of the study, with wind displacing coal used for sensitivity analysis. Wind displacing the typical grid mix is not considered further.

Placing a value on the avoided emissions: The technique used in this study to estimate the value of the avoided emissions is that used by the UK Treasury to assess the societal cost of emissions of carbon dioxide.

HM Treasury (2002) reviewed all available studies on the cost of the physical impacts of climate change. The most sophisticated of the published studies reviewed produced a marginal damage estimate of £70/tC (2000 prices) for carbon emissions in 2000. This increases by approximately £1 per tonne in each subsequent year to account for increasing damage costs over time.

This figure is subject to significant uncertainty and excludes consideration of the probability of "climate catastrophes" (and socially contingent impacts of climate change that could, potentially increase the size of damages considerably.

As such, the Treasury settles on a figure of £70 per tonne of carbon (in 2000 prices) as an "illustrative point estimate" of relevant damages, using an upper value of £140 and a lower value of £35. This increases by approximately £1 per tonne in each subsequent year to account for increasing damage costs over time (HM Treasury, 2002).

These three values will be used to represent low, medium and high values of carbon. One tonne of carbon is equal to 3.67 tonnes of CO_2, giving the following figures:

Low	£35/tonne carbon or £9.50/tonne CO_2
Medium	£70/tonne carbon or £19.10/tonne CO_2
High	£140/tonne carbon or £38.15/tonne CO_2

A GDP deflator (HM Treasury, 2006) has been used to convert the values into 2006 prices. Thus, the 2006 value of a tonne of carbon is £87, which equates to a value of £24/€35 per tonne of carbon dioxide.

The annual value of avoided emissions, using the central value of carbon increases from £19.5 million in the first year of full operation, to £25.4 million in the 25th year of operation.

2.4. Non-market costs

2.4.1. Carbon dioxide released during manufacture and construction

This figure is based upon a Life Cycle Analysis study showing that onshore windfarms pay back the carbon dioxide released during their manufacture and construction within 0.29 years of operation (Schleisner, 1999).

The value used is 0.29 of a year's worth of avoided carbon dioxide, based on the same conversion factor used for the main avoided emissions calculation. This is then multiplied by the same value of carbon that has been used to value the avoided emissions using the social cost of carbon methodology. It is then divided equally over the three years of construction. Using the central value of carbon, this cost is £1.8 million for each year of construction.

It is important to note that no similar calculation has been undertaken for the counterfactual investment option of a gas-fired power station. This follows the ExternE (European Commission, 1999) methodology, whereby the fossil fuel cycle only takes into account emissions from operation, as these dwarf the emissions from construction. For a windfarm, conversely, the only significant emissions are from manufacture and construction.

2.4.2. Carbon dioxide released through deforestation

One thousand and seventy hectares of commercial plantation will be removed as part of the site preparation for the windfarm. In the absence of the proposed windfarm, this same area would be deforested, but the felling would take place over the period to 2098 rather than to 2008.

However, there would be no resulting net increase in CO_2 emissions. The use of these trees meets demand that would otherwise be met by the felling of alternative trees. Or if the trees were used for co-firing, they might well displace coal, thus reducing net CO_2 emissions.

2.4.3. Visual and noise disamenity for residents and visitors

The principal external costs of windfarms are visual impact and noise. Both forms of impact can be assessed using market and non-market benefits assessment information. However, the application of these methods to specific wind installations is minimal and this complicates our analysis.

In this section we establish a method to value the impacts to residents and visitors based on transferring and calibrating existing landscape willingness to pay (WTP)/value information. Our analysis will focus on visual impact that reduces these landscape values. The Environmental Statement has determined that in contrast to the visual impact, the noise impact of the operational windfarm is not likely to be significant.

Damages to residents can be measured in two ways. A revealed preference approach can be used to consider the impact of wind turbines on house price values for properties in the vicinity. This "hedonic" pricing approach has been used to consider the impacts of pylons and cables in the UK (Atkinson et al., 2005). The main difference with pylons and cables is the presence of a potential health impact, which can be valued highly because of a so-called "dread" factor. This confounding effect means that using revealed data from pylon studies may produce unreliable results when transferred to wind installations.

For the purposes of this analysis and in the absence of site-specific evidence, we need to make assumptions about how any benefit information can be derived by benefits transfer.

Landscape amenity valuation: The method proposed to value visual impact to landscape from wind turbines considers damaged use values among residents and visitors.

The use damage estimate considers the nature of intrusion (pre and postconstruction), exposure to intrusion (number of residents and visitors per year), and unit landscape values (WTP values for the actual intrusion category or alternatively WTP for landscape types).

A range of landscape values can be found in studies by Garrod and Willis (1995, 1997), Hanley et al. (2005), Price (1993) and Hamilton and Schwann (1995).

Typically, the available studies relate to valuation of amenity of areas under agri-environmental schemes. Such areas will have higher amenity value than the Clyde location and we recognize that statutory duties preclude resource development in these areas. In the case of the Clyde site, recreational shooting under the control of landowners takes place, but use of the site for informal recreation such as walking/cycling is considered to be limited (Land Use Consultants, 2004). The Southern Upland Way does, however, pass near the southern boundary of the site, with an estimated 5212 visitors to the two sections of the route closest to the site (Land Use Consultants, 2004). In any case, choosing these WTP values will likely overstate the damage estimate here.

Cost calculations are detailed in the following steps:

Step 1: *Establish and measure landscape impact.* These stages describe how we determine the monetary equivalent of a landscape impact caused by turbines. The method applies a benefits transfer approach. In other words, we do not undertake any primary valuation studies to elicit WTP, but attempt to adjust existing amenity value information.

We suggest site degradation is defined by an ordinal impact scale (see Table 2), which can be associated with WTP reduction factors. In other words, the WTP or value of a pristine landscape is reduced successively by higher levels of intrusion. The estimates in the table are arbitrary but given time these intrusion classes and factors could be elicited as part of an on-site survey conducted among a sample of visitors and residents.

Step 2: *Establish WTP.* Mean landscape WTP is a value transferred from a valuation study covering resident and visitor valuation of a similar landscape type. Table 3 provides a range of transfer values from various landscape studies. The landscape types referenced by these values correspond to different landscape types across the UK. The study by Bullock and Kay (1997) provides a value that can be transferred to provide an approximate value in the Clyde case.

Table 2
Landscape intrusion scale adapted from Price (1993)

Landscape intrusion scale	WTP reduction factor (%)	
Unsightly	80	Implies factor WTP*0.2
Undistinguished	50	Implies factor WTP*0.5
Slight intrusion	40	Implies factor WTP*0.6
Distinguished/attractive	30	Implies factor WTP*0.7
Superb/excellent	10	Implies factor WTP*0.9
Spectacular/exceptional	0	Implies factor WTP*1

Step 3: *Specify exposure.* Exposure to visual impact pre and postconstruction is defined as the number of residents and visitors likely to experience the landscape impact. While there may often be reduced visibility due to rain or mist, we do not reduce the values to take account of this. We suggest that apart from detriment to outstanding beauty spots, visitation rates can be assumed constant for years following construction.

We have used a Geographical Information System (GIS) to accurately establish the number of residents (and number of households) within the Zone of Visual Influence (ZVI) as outlined in the Environmental Statement. The outer limit of the ZVI is 35 km from the perimeter of the site. Within this area there are just over 220,000 residents (just under 98,000 households).

The Environmental Statement contains GIS output illustrating the areas within the ZVI from which certain numbers of turbine tips can be seen. The numbers are grouped into ranges, such as 1–30, 31–60, etc. However, there is no attendant information as to how many people are resident in these areas. We obtained the source data for this illustration, and using a GIS, overlaid it with unit postcode data which contains population and household numbers for each individual postcode. This information was then grouped by distance from the perimeter of the site, in concentric bands of 5 km width. The results are shown in Tables 4 and 5. Table 4 shows the number of households, while Table 5 shows the number of residents.

It is clear from both tables that despite the fact that the windfarm contains 173 turbines, it will not be possible for all turbines to be viewed simultaneously from any residence within 35 km of the perimeter. There are nine households from which 116–145 turbine tips will be visible, and a further nine from which 90–115 tips will be visible, and these are located between 20 and 25 km from the site boundary.

Exposure for residents will vary both with the number of turbine tips visible, and the distance from the perimeter of the site. We will apply a "distance decay" function and also calibrate the impact depending on the number of turbine tips visible.

For visitors we will use the figure supplied in the Environmental Statement for the numbers using relevant

Table 3
Environmentally sensitive area landscape values (WTP, £ household/y)

Study	Country	WTP residents (£)	WTP visitors (£)	General public (£)	Base year
Hanley et al. (1998)—Breadalbane ESA	UK	31.43	73.00	22.02	1995
Hanley et al. (1996)—Machair ESA	UK	13.66		13.37	1995
Garrod et al. (1994)—South Downs ESA	UK	27.52	19.47	1.98	1992
Garrod et al. (1994)—Somerset Levels ESA	UK	17.53	11.84	2.45	1992
Gourlay and Willis (1995)—Loch Lomond ESA	UK	20.60	1.98 per visit		
Gourlay and Willis (1995)—Stewarty ESA	UK	13.00	2.53 per visit		
Bullock and Kay (1997)—Southern Uplands ESA	UK	69.00		83.00	1995
Garrod and Willis (1995)—WTP to maintain ESA scheme in England	UK			36.35	1994

Table 4
The number of households in areas from which different numbers of turbine tips are visible, grouped by distance from the site perimeter

	Number of turbine tips visible					
	1–30	31–60	61–90	91–115	116–145	146–173
Distance from site boundary (km)						
0–5	255	122	98	0	0	0
5–10	446	62	0	0	0	0
10–15	1653	43	0	0	0	0
15–20	3192	188	29	0	0	0
20–25	2790	323	9	9	9	0
25–30	5341	1066	11	0	0	0
30–35	13167	487	1652	0	0	0

Table 5
The number of residents in areas from which different numbers of turbine tips are visible, grouped by distance from the site perimeter

	Number of turbine tips visible					
	1–30	31–60	61–90	91–115	116–145	146–173
Distance from site boundary (km)						
0–5	638	307	246	0	0	0
5–10	1011	134	0	0	0	0
10–15	3610	99	0	0	0	0
15–20	7193	433	61	0	0	0
20–25	6904	784	22	22	22	0
25–30	12751	2549	22	0	0	0
30–35	29804	1263	3469	0	0	0

sections of the Southern Upland Way. It is estimated that annually there are 5212 visitors to the two sections of the Southern Upland Way closest to the site (Land Use Consultants, 2004).

Step 4: *Establish change in landscape value*. Damage = site degradation (%) × exposure to visual damage × mean landscape WTP.

This should be calculated for each class of residents and visitors who suffer exposure, and summed to give the total damage.

Application: Assume the Clyde Valley is constructed in a landscape similar to the Environmentally Sensitive Areas considered by Bullock and Kay (1997). The latter study provides a residents' WTP value for landscape preservation that we assume to be the value placed on a landscape without windfarms. This is damaged by turbines, and we need to determine the extent of this damage. The same study does not provide a value for visitors, and so we transfer the benefit estimate shown for the South Downs ESA (Garrod et al., 1994). Consider the value change applies to the 71,344 residents who can see at least 1 turbine tip from within the 35 km ZVI and the estimated 5212 visitors per annum to the two sections of the Southern Upland Way closest to the site (Land Use Consultants, 2004).

Visitors: Assume around 2500 suffer "unsightly" intrusion, and 2712 are in the "undistinguished" impact category. From Table 2 implied impact scores are 80% and 50% of WTP values, respectively. From Table 3 non-resident WTP £19.47/year.

Visitor WTP reduction "unsightly" from Table 3 = (0.2 × £19.47) = £3.80

Welfare reduction per visitor per year = £19.47−£3.80 = £15.67

Visitor WTP reduction "undistinguished" = (0.5 × £19.47) = £9.70

Welfare reduction per visitor per year = £19.47−£9.70 = £9.77

Visitor weighted loss = (2500 × £15.67) + (2712 × £9.77) = £65671.2 per year

Note that this assumes constant visitor numbers, but these may also change in the postconstruction era. They may well increase, as visitors may be attracted to the viewing platform. It is likely that such visitors, through self-selection, might have a positive view of the windfarm. Moreover, as discussed below, we may also wish to assume a factor for a changing social perception of wind energy in the environment. This may vary between residents and visitors. However, for the time being, we incorporate this estimate into our spreadsheet.

Residents: The number of residents in areas from which different numbers of turbine tips are potentially visible was indicated in Table 5. These residents are grouped by distance from the site perimeter in 5 km intervals.

Following the landscape intrusion scale outlined in Table 2, those who can view 61–90 turbine tips are deemed to suffer "unsightly" intrusion. This gives an implied impact score of 80% of WTP values, taken from Table 3 to be £69 per resident per year. This and other impact scores are shown in Table 6.

The reduced visual intrusion through increased distance from the site perimeter is accounted for by adjusting the weighting for each 5 km grouping. Those residents within 0–5 km of the site perimeter are attributed the full value

Table 6
Impact scores and related annual welfare loss per resident based on number of turbine tips visible, taking a residents WTP of £69 from Bullock and Kay (1997)

No of turbine tips visible	Impact score (%)	Welfare loss per resident/year (£)
1–30	70	48.30
31–60	75	51.75
61–90	80	55.20
91–115	85	58.65
116–145	90	62.10
146–173	N/A	N/A

Table 7
Weightings given to residents' WTP value based on distance from perimeter of site

Distance from site perimeter (km)	Weighting (%)
0–5	100
5–10	75
10–15	50
15–20	25
20–25	15
25–30	10
30–35	5

based on the visibility impact scores. The weightings for this and each subsequent distance band are shown in Table 7. These weighting estimates are arbitrary but given time they could be elicited as part of an on-site survey conducted among a sample of residents.

As an example, the visual disamenity for the 134 residents who can see 31–60 turbine tips and live 5–10 km from the site is calculated as follows:

> The 134 residents have a visual impact score of 75%, which means an individual annual welfare loss of £51.75 (£69 × 0.75). Cumulatively this is £6934.50. This is then weighted by distance, so 75% of this value is taken, giving a weighted cumulative annual welfare loss of £5200.87.
>
> This process is repeated for all the residents in each visibility and distance grouping, giving a total welfare loss of £501,533.41 per year. Combining this with the welfare loss to visitors gives an overall welfare loss due to visual disamenity of £567,000 per year.

Changing perceptions of wind energy in the environment: Two elements need to be mentioned at this point. The first is that anecdotal evidence appears to suggest that residents become accustomed to windfarms, which engender a sense of civic pride in installations that are effectively agents of environmental good. No studies have assessed this element in terms of a monetary valuation, but in traditional economic terms, it would suggest that the value of any disamenity impact should fall through time rather than being an invariant cost in the CBA. Local part-ownership of a windfarm may also improve perception among residents (Toke, 2005), along with local employment or donations for community facilities through planning gain from the development.

The second factor is that visual intrusion is essentially reversible. It is unclear whether the transferred WTP values we might use here are for changes that were portrayed as irreversible. This has to make a difference.

2.4.4. Non-use disamenity

The visual impact of a windfarm is essentially site specific and varies according to the existing landscape, and the level to which residents and visitors are "exposed" to the impact. A complicating factor is added by the non-use disamenity of landscape change. In other words, beyond local impacts, wider populations of the UK may have preferences over the impacts of installations, irrespective of whether they actually experience them directly. They are simply damaged in a passive way by the knowledge of installations influencing landscape form.

Interest in the concept and measurement of non-use value is not new and there has been considerable theoretical and methodological debate in the area of environmental economics concerned with nature and heritage conservation. This literature has developed the basis for using stated preference methods (contingent valuation and choice experiments) to determine the economic or monetary value of non-use impacts. This is a development that is now recognized as a legitimate process in public appraisal (e.g. the Treasury Green Book).

The existence of non-use or passive value is intuitive for celebrated and iconic landscapes, but not necessarily so for all landscapes. It is, however, difficult to argue that these values do not exist and the existence of empirical estimates does give substance to a popular debate that is largely uninformed by data.

Unfortunately, the stated preference literature does not provide general rules to help us determine the size of non-use value nor how values might change in relation to different landscapes or the proximity of the individual preference holder to the environmental attribute in question. To deal with this, our analysis can either attempt to transfer existing estimates from previous studies or determine these impacts on a case-by-case basis. Accounting for this impact is more complex than the use (residents and visitor) impacts, which can at least be calibrated by a fixed number of "damaged" individuals, i.e. a range can be placed by measuring residents in proximity to installations and visitor numbers to the vicinity.

There are several existing valuation studies addressing the impact of wind energy (Alvarez-Farizo and Hanley, 2002; Ek, 2002; Navrud, 2004) These studies suggest that non-market impacts can be as high as £17 per household per year. A study that explicitly considers the nature of visual landscape impact in Scotland has been conducted by Bergmann et al. (2006). But even this study does not actually show specific installations in a landscape context. Instead, the study uses stated preferences to consider the impacts of infrastructure (visual, wildlife and air pollution) in a somewhat abstract way and the values that emerge from the choice experiment are not site or project specific. In essence, the authors target the non-use category of respondents mentioned above, and effectively the values they derive can be argued to apply to the whole population. These values are then assigned to what they consider to be typical infrastructure intrusions, which in their onshore wind case amount to a 160 MW windfarm. There are many possible criticisms of this study. The main criticism is that respondents to the survey never actually get to see a case of windfarm intrusion on which to base their responses.

Moreover, the distinctions between low, moderate and high landscape impacts are unclear and some of the econometric models suggest that impacts are actually statistically insignificant, thus rendering the results of limited value.

The upper limit of damages suggested in the Bergmann study is that the average Scottish household suffers an annual welfare loss of £19.40 from the major landscape impact. The study suggests that this impact is associated with a "large" windfarm (160 MW—80 turbines). The 622 MW Clyde project, has more than double the number of turbines (173) and almost four times the installed capacity of this hypothetical example. If this is truly an annual welfare loss in the presence of the Clyde proposal, then the aggregate value (if multiplied by the 2.1 million Scottish households) is £40.74 million per year. At this point, and in the absence of primary research, we suggest that this is the upper limit of the non-use damage attributable to the Clyde installation, even though the true estimate is likely to be lower.

There are several reasons for this. The first is that the Bergmann estimate is not site specific and in fact may lead respondents (in their stated preference study) to infer damages associated with all wind installations, including assumptions about iconic landscapes, rather than at specific locations of lesser scenic value.

The second is the population over which this value might be applied. For the sake of argument in determining our "worst case", it could potentially be that all Scottish households are damaged and that the value of £19.40 should be ascribed to each household. But for landscapes of lesser scenic value, it could reasonably be expected that the value held will diminish with distance from the site. This suggests that fewer households will be damaged, thereby leading to a lower aggregate value of damages.

Further reasons for adjusting the extent of the Bergmann estimate can be justified with reference to the nature of the respondent sample used in the study (i.e. the balance between rural and urban respondents). Furthermore, the possibility that opposition to wind installations might diminish through time with increasing acceptability of the technology would mitigate against using the Bergmann estimate as an invariant annual value. However, we do not attempt to adjust the value, nor do we introduce alternative estimates for non-use value at this point. The non-use disamenity value of £40.74 million will therefore be attributed to each year of the project's construction and operation.

3. Results and sensitivity analysis

All cost and benefit streams are discounted at the UK Treasury's social discount rate of 3.5%, except for the avoided fuel cost stream. In most scenarios this is discounted at a rate of −1.1% for gas, and −1.3% for coal, a figure obtained by using the Capital Asset Pricing Model (CAPM) approach (Awerbuch, 2006). For comparison there are two scenarios, one each for coal and gas, where the fuel cost stream is discounted at the Treasury rate.

From Table 8 it can be seen that for the eight main scenarios considered, the project delivers a positive net present value ranging from £780 million to £2.3 billion before accounting for the non-use disamenity impact. Applying the non-use disamenity present value of £720 million (based on a non-use welfare loss of £19.40 for each of the 2.1 million Scottish households (Bergmann et al., 2006), the project still returns a positive net present value for each scenario. This ranges from £60 million to £1.5 billion.

The final row indicates the maximum annual household non-use welfare loss, for each of the 2.1 million Scottish households, that could be sustained while still returning a positive net present value under each scenario. That is to say, the project would still deliver a welfare gain to Scotland even if this non-use disamenity value were held. This figure ranges from £21.01 up to £60.97.

It is of greatest interest to note the sensitivity of these results to the number of households to which the non-use value of £19.40 is applied. If the figure were applied to 2.28 million rather than 2.1 million households, the net present value for the gas scenario where the fuel is discounted at the Treasury rate would be negative.

3.1. Sensitivity to gas prices

It can be seen from Table 8 that in all but one of the scenarios (wind displaces gas, with a low value of carbon), the benefits arising from avoided GDP losses and carbon savings are greater than the sum of the costs (excluding the non-use disamenity value). That is to say, in an analysis that did not take account of the non-use disamenity value, even if the avoided costs of gas were to drop to zero, the benefits would outweigh the costs in most scenarios. Thus, it is the application of the non-use value that renders the avoided gas costs so significant for the project NPV.

The results in Table 8 refer to a gas price of 35 p/therm. Table 9 shows the sensitivity to gas prices, using a high price of 52 p/therm, and a low price of 21 p/therm, as used in the UK Government's Energy Review (DTI, 2006).

In all but one of the scenarios in Table 9, the project still returns a positive NPV even with the inclusion of the £19.40 non-use figure applied to 2.1 million households. In the one scenario where a negative NPV is returned, the maximum annual household welfare loss, for each of the 2.1 million Scottish households, that could be sustained while still returning a positive net present value would be £13.56.

4. Discussion

The significance of the non-use value is clear from Table 8. It is roughly twice the size of all the other cost categories put together for the gas counterfactual, and over four times the total of all other costs for the coal counterfactual.

Table 8
Summary Clyde present value costs and benefits

Summary Clyde present value costs and benefits over assumed 28-year project life (£millions)	Wind displaces gas				Wind displaces coal			
	CAPM fuel discount	Treasury discount rate	CAPM fuel discount		CAPM fuel discount	Treasury discount rate	CAPM fuel discount	
	Central value of carbon		High value of carbon	Low value of carbon	Central value of carbon		High value of carbon	Low value of carbon
Costs								
Construction	230	230	230	230	65	65	65	65
Operation and maintenance	36	36	36	36	−7	−7	−7	−7
Extra balancing costs to network	48	48	48	48	48	48	48	48
Rent	30	30	30	30	30	30	30	30
CO_2 released during manufacture and construction	5	5	11	3	12	12	24	6
Visual disamenity for residents and visitors	10	10	10	10	10	10	10	10
Non-use disamenity	0	0	0	0	0	0	0	0
Total costs	359	359	364	356	157	157	169	151
Benefits								
Avoided fuel costs	1357	691	1357	1357	769	379	769	769
Avoided GDP losses	102	102	102	102	102	102	102	102
Avoided carbon emissions	345	345	689	172	780	780	1560	390
Total benefits	1804	1138	2148	1631	1651	1261	2431	1261
Net project benefit NPV = benefits−costs	1445	780	1784	1275	1494	1104	2262	1110
Applying non-use disamenity value to project NPV								
Bergmann et al. (2006) £19.40 non-use disamenity value applied to 2.1 million Scottish households	720	720	720	720	720	720	720	720
Net project benefit after application of non-use value	726	60	1065	555	774	384	1542	390
Maximum annual household non-use disamenity value that would still return a positive NPV (£)	38.96	21.01	48.11	34.38	40.26	29.75	60.97	29.91

Table 9
Sensitivity to gas prices

Sensitivity to gas prices	CAPM fuel discount	Treasury discount rate	CAPM fuel discount	
	Central value of carbon		High value of carbon	Low value of carbon
Gas price 21 p/therm				
Project NPV before non-use disamenity	903	503	1242	733
Applying non-use disamenity value to project NPV				
Bergmann et al. (2006) £19.40 non-use disamenity value applied to 2.1 million Scottish households	720	720	720	720
Net project benefit after application of non-use value	183	−217	522	13
Maximum household non-use disamenity value that would still return a positive NPV (£)	24.33	13.56	33.47	19.75
Gas price 52 p/therm				
Project NPV before non-use disamenity	2105	1115	2444	1935
Applying non-use disamenity value to project NPV				
Bergmann et al. (2006) £19.40 non-use disamenity value applied to 2.1 million Scottish households	720	720	720	720
Net project benefit after application of non-use value	1424	1135	2483	1254
Maximum household non-use disamenity value that would still return a positive NPV (£)	58.78	30.6	66.92	53.2

As mentioned above, the cumulative non-use value is based on the arbitrary choice of applying the £19.40 to all Scottish households, of which there happen to be 2.1 million. Under the gas scenario where the fuel is discounted at the Treasury rate, the net present value is negative when the non-use figure is applied to 2.28 million households, a Scottish households figure that would arise if the Scottish/English border happened to be drawn 30 miles further south.

This raises an important issue for the application of non-use value—the placing of bounds. Is an administrative boundary really appropriate? Would a windfarm that is closer to Carlisle than it is to Perth not have a greater non-use effect on those immediately over the border in England? If a similar windfarm were built in England should the non-use value be applied to all 21 million households, or is there a distance decay function that can more readily capture the non-use disamenity value of a specific installation?

There is also the issue of how this non-use value might vary through time. With an increasing number of windfarms being developed, would the non-use disamenity value associated with each marginal installation increase or decline? If tackling climate change becomes a far more significant priority as far as the public are concerned, would there be a greater acceptance of wind installation, marked by a declining non-use disamenity value?

5. Conclusion

The analysis presented in this report demonstrates that under standard assumptions, with the windfarm displacing a gas-fired power station, and including a reasonable accounting for local disamenity impacts, the Clyde project delivers a net welfare gain of £1445 million.

When the only available estimate for the non-use disamenity value for a large (160 MW, 80 turbine) windfarm in Scotland (of £19.40 per household per annum for all 2.1 million Scottish households) is imputed, this reduces the welfare gain to £726 million. What this result means is that the Clyde project still delivers a net welfare gain to society.

That this non-use disamenity value can reasonably be applied to the Clyde windfarm in this way is far from certain. There are some very good reasons for doubting that this represents the true non-use value associated with this project.

A number of research questions follow from this analysis. The most pressing appears to be the investigation of the non-use value cost category associate with windfarms. Specifically, further investigation is warranted to determine how this value varies across survey respondents when they are given further information on the location of windfarms. It would seem inappropriate to assume that this value is not invariant with location of both the windfarm and the respondent, the number of windfarms or through time. But there is currently no research that proves this.

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References

Alvarez-Farizo, B., Hanley, N., 2002. Using conjoint analysis to quantify public preferences over the environmental impacts of wind farms. Energy Policy 30 (2), 107–116 (in Spain).

Atkinson, G., Day, B., Mourato, S., 2005. Underground, overground? Measuring the disamenity from electricity transmission lines. In: Pearce, D.W. (Ed.), Valuing the Environment in Developed Countries: Case Studies. Edward Elgar, Cheltenham forthcoming.

Awerbuch, S., 1995. Market-based IRP: it's easy!!! The Electricity Journal, April.

Awerbuch, S., 2003. The True Cost of Fossil-Fired Electricity in the EU: A CAPM-based Approach. Power Economics, May 2003.

Awerbuch, S., 2005. The role of wind generation in enhancing Scotland's energy diversity and security: a mean–variance portfolio optimization of Scotland's generating mix. Report prepared for Airtricity, Greenock, Scotland.

Awerbuch, S., 2006. Personal communication—current societal discount rate estimate for avoided coal and gas streams.

Awerbuch, S., Sauter, R., 2005. Exploiting the oil-GDP effect to support renewables deployment. Energy Policy, in press, Corrected Proof. Available online 21 June 2005.

Bergmann, A., Hanley, N., Wright, R., 2006. Valuing the attributes of renewable energy investments. Energy Policy 34, 1004–1014.

Bullock, C., Kay, J., 1997. Preservation and change in the upland landscape: the public benefits of grazing management. Journal of Environmental Planning and Management 40, 315–334.

Burall, P., 2004. Putting wind turbines in their place. Town and Country Planning 73 (2), 60–63.

BWEA, 2005. Wind and the UK's 10% target. Briefing Sheet, British Wind Energy Association, available on the BWEA website. 〈http://www.bwea.com/pdf/briefings/target-2005-small.pdf〉 (accessed January 2006).

Carbon Trust, 2006. 'Expert Info—Conversion Factors' page on the Carbon Trust website 〈http://www.thecarbontrust.co.uk/energyCMS/CarbonTrust/pages_preview/page_64.asp〉 (accessed January 2006).

Dale, L., Milborrow, D., Slark, R., Strbac, G., 2004. Total cost estimates for large-scale wind scenarios in UK. Energy Policy 32, 1949–1956.

Defra, 2006. Guidelines for company reporting on Greenhouse Gas Emissions, available on the Defra website 〈http://www.defra.gov.uk/environment/business/envrp/gas/index.htm〉 (accessed January 2006).

DTI, 1999. New and renewable energy: prospects for the 21st century: supporting analysis, ETSU 〈http://www.dti.gov.uk/renewables/publications/pdfs/support.pdf〉 (accessed March 1999).

DTI, 2002. The Renewables Obligation Order 2002: Regulatory Impact Assessment Department for Trade and Industry 〈http://www.dti.gov.uk/access/ria/renewables.htm〉.

DTI, 2005. Digest of UK Energy Statistics 2005, Table 5.10, 'Plant loads, demand and efficiency' 〈http://www.dti.gov.uk/energy/inform/energy_stats/electricity/dukes05_5_10.xls〉.

DTI, 2006. The Energy Challenge: Energy Review. HMSO, London.

ECI, 2005. Wind power and the UK wind resource. A report for the Department for Trade and Industry, Environmental Change Institute, Oxford 〈http://www.eci.ox.ac.uk/renewables/UKWind-Report.pdf〉.

Ek, K., 2002. Valuing the Environmental Impacts of Wind Power, a Choice Experiments Approach. Cited in Ladenburg, J.A. Dubgaard and Jesper Tranberg (2006).

European Commission, 1999. ExternE: Externalities of Energy. National Implementation, Brussels.

Garrod, G.D., Willis, K.G., 1995. Valuing the benefits of the South Downs environmentally sensitive area. Journal of Agricultural Economics 46 (2), 160–173.

Garrod, G., Willis, K., 1997. The non-use benefits of enhancing forest biodiversity: a contingent ranking study. Ecological Economics 21, 45–61.

Garrod, G.D., Willis, K.G., Saunders, C.M., 1994. The benefits and costs of the Somerset Levels and Moors ESA. Journal of Rural Studies 10 (2), 131–146.

Gourlay, D., 1995 Loch Lomond and Stewartry ESAs: a study of public perceptions of policy benefits. Unpublished Ph.D. thesis, University of Aberdeen.

Hamilton, S., Schwann, G., 1995. Do high voltage electric transmission lines affect property values? Land Economics 71 (4), 436–444.

Hanley, N., Bergmann, A., Kim, Y., 2005. The environmental impacts of renewable energy: an investigation of public preferences. Working Paper, University of Stirling 〈http://www.economics.stir.ac.uk/staff/hanley/EnergyEconomicsPaper.pdf〉.

Hanley, N., Simpson, L., Parsisson, D., Macmillan, D., Bullock, C., Crabtree, R., 1996. The valuation of the conservation benefits of Environmentally Sensitive Areas. Final Report to SOAEFD, University of Stirling and Macaulay Land use Research Institute.

Hanley, N., MacMillan, D.C., Wright, R.E., Bullock, C., Simpson, I., Parsisson, D., Crabtree, J.R., 1998. Contingent valuation versus choice experiments: estimating the benefits of Environmentally Sensitive Areas in Scotland. Journal of Agricultural Economics 49 (1), 1–15.

HM Treasury, 2002. Estimating the social cost of carbon emissions. Government Economic Service Working Paper 140, HM Treasury, London.

HM Treasury, 2006. GDP Deflators Index page on Treasury website 〈http://www.hm-treasury.gov.uk/economic_data_and_tools/gdp_deflators/data_gdp_index.cfm〉 (accessed February 2006).

Ilex Energy Consulting, Strbac, G., 2002. Quantifying the system costs of additional renewables in 2020. DTI 〈http://www.dti.gov.uk/energy/developep/080scar_report_v2_0.pdf〉.

Ilex Energy Consulting, 2005. Storage, gas prices and security of supply.

Ilex Energy Consulting, 2006. Projections of the price for wholesale electricity in Great Britain.

Kennedy, S., 2005. Wind power planning: assessing long-term costs and benefits. Energy Policy 33 (13), 1661–1675.

Land Use Consultants, 2004. Clyde Windfarm Environmental Statement, September 2004.

MacLeod, M., Moran, D., Spencer, I., 2006. Counting the cost of water use in hydroelectric generation in Scotland. Energy Policy 34/15, 2048–2059.

Milborrow, D., 2005. Submission to Environmental Audit Select Committee, Keeping the lights on: Nuclear, Renewables and Climate Change 〈http://www.hm-treasury.gov.uk/media/E7C/A6/climate-change_BWEA_2.pdf〉.

MacDonald, M., 2003. The Carbon Trust and DTI: Renewables Network Impact Study, Annex 4: Intermittency Literature Survey and Roadmap 〈http://www.thecarbontrust.co.uk/carbontrust/about/publications/Annex4.pdf〉.

National Grid Transco, 2004. Seven Year Statement.

Navrud, S., 2004. MILJØKOSTNADER AV VINDKRAFT I NORGE Sammendragsrapport til SAMRAM-programmet.Norges Forskningsråd.Notat. Institutt for Økonomi og Ressursforvaltning.Universitetet for Miljø-og Biovitenskap (UMB).

Ofgem, 2004. The Scottish Parliament Enterprise and Culture Committee: Renewable Energy in Scotland Enquiry, submission from Ofgem, 10th February 2004 〈http://www.scottish.parliament.uk/business/committees/enterprise/inquiries/rei/ec04-reis-ofgemfollowup.htm〉.

Oxera, 2004. Results of Renewables market modelling. Report for the DTI 〈http://www.dti.gov.uk/renewables/policy/oxeraresults.pdf〉 (accessed February 2004).

Pasqualetti, M.J., Gipe, P., Righter, R.W. (Eds.), 2002. Wind Power in View: Energy Landscapes in a Crowded World. Academic Press, San Diego.

Price, C., 1993. Applied landscape economics: a personal journey of discovery. Journal of Environmental Planning and Management 36 (1), 51–63.

Royal Academy of Engineering, 2004. The Cost of Generating Electricity. A Study carried out by PB Power for The Royal Academy of Engineering ⟨http://www.raeng.org.uk/news/publications/list/reports/Cost_of_Generating_Electricity.pdf⟩ (accessed March 2004).

Schleisner, L., 1999. Life cycle assessment of a wind farm and related externalities. Renewable Energy 20, 279–288.

Scottish Executive, 2003. Securing a Renewable Future: Scotland's Renewable Energy ⟨http://www.scotland.gov.uk/Resource/Doc/47034/0014765.pdf⟩.

Scottish Executive, 2005. Scotland's Renewable Energy Potential, Future Generation Group Report ⟨http://www.scotland.gov.uk/Resource/Doc/69582/0017404.pdf⟩.

Scottish Executive, 2006a. Scottish Executive response to UK Energy Review ⟨http://www.scotland.gov.uk/Resource/Doc/129622/0030898.pdf⟩ (accessed June 2006).

Scottish Executive, 2006b. Matching Renewable Electricity Generation with Demand ⟨http://www.scotland.gov.uk/Publications/2006/04/24110728/0⟩.

Scottish Renewables, 2006. Delivering the new generation of energy: route map to Scotland's renewable future ⟨http://www.scottishrenewables.com/data/reports/SRF%20Route%20Map.pdf⟩.

Simpson, D., 2004. Tilting at Windmills: The Economics of Wind Power, David Hulme Institute, Edinburgh, Occasional Paper Number 65 ⟨http://www.davidhumeinstitute.com/DHI%20Website/publications/hop/Wind%20Power%20paper.pdf⟩.

Toke, D., 2005. Explaining wind power planning outcomes: some findings from a study in England and Wales. Energy Policy 33, 1527–1539.

Warren, C., Lumsden, S., O'Dowd, S., Birnie, R., 2005. Green on Green: public perceptions of wind power in Scotland and Ireland. Journal of Environmental Planning and Management 48 (6), 853–875.