Payments for Ecosystem Services (PES) for climate regulation in UK farmlands

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Declaration

The candidate confirms that the work submitted is her own, except where work, which has been developed into part of jointly-authored publication, has been included. The contribution of the candidate and other authors to this work are indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

The work in Chapter 4 has been developed into a jointly authored publication: Abson, D.J., Termansen, M., Pascual, U., **Aslam, U.**, Fezzi, C., Bateman, I. (2013) Valuing Climate Change Effects Upon UK Agricultural GHG Emissions: Spatial Analysis of a Regulating Ecosystem Service. *Environmental Resource Economics.*

The paper is now available online at doi: 10.1007/s10640-013-9661-z.The candidate is a contributing author on this article. She has collated the data for estimations of the carbon and greenhouse gas stocks and flows, calculated these stocks and flows for land use changes, and estimated the changes in regulatory service for climate change scenarios. Dave Abson helped in the scenarios estimations and carried out the carbon valuation section of the paper and the role of lead author of the paper. Mette Termansen and Unai Pascual provided overall research development and methodological advice as well as extensive manuscript review. Carlo Fezzi and Ian Bateman developed the land use model which was used for the climate scenario estimations.

Chapter 4 has also been published as part of the Chapter 22: Economic Values from Ecosystems in the *Technical report* of the UK National Ecosystem Assessment (UKNEA) Report, 2011.

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Abstract

This thesis aims to investigate the design of payments for ecosystem services (PES) for climate regulation service provided by agriculture. The research provides a better understanding of how agroecosystems can contribute towards meeting the UK's targets to reduce GHG emissions. The research comprised of three main stages. Stage 1 explicitly models the effect of climate change on land use change decisions and its subsequent effect on climate regulatory service provided by agriculture, under high and low emission scenarios defined by the UK Climate Impacts Programme for the period 2004-2060. This includes a comprehensive study of the contribution of the UK farmlands towards GHG emissions, from both changes in carbon stocks and changes in annual flows as a result of predicted land use change due to climate change. Stage 2 evaluates PES scheme design for farmers' willingness to contribute towards enhancing the climate regulation as an environmental service. This stage employed Choice Experiment to elicit farmers' choices for two potential payment scenarios, designed for both arable and livestock farmers. It was found, in general, that farmers have a strong aversion to drastic changes in land use management; however, flexibility in certain scheme attributes and appropriate compensations can help to attract farmers. Stage 3 includes a carbon abatement cost analysis for the two potential schemes and provides spatial pattern of the carbon costs through PES schemes across UK. Marginal Abatement Carbon Costs were estimated by calculating the price of reductions in carbon emissions as a result of the adoption of alternative payment schemes. Furthermore, spatial analysis was conducted to provide a linkage between the cost of carbon mitigation and spatial attributes to identify the most cost-effective areas that can be preferentially targeted through the implementation of PES schemes. Overall the thesis confirms that although the agriculture sector contributes to the annual emissions of the UK, it has the potential to contribute towards the mitigation of these emissions as well and highlights the scope of PES schemes for achieving emission reductions. Overall, it assesses the effect of scheme design and socioeconomic characteristics on the effectiveness of a scheme, in terms of its uptake by land managers. It also informs the policy makers about the abatement potential and cost-effectiveness of schemes specifically targeting arable and livestock farms.

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Chapter 1 Introduction

1.1. Introduction

Ecosystem services (ES) are the benefits derived from ecosystems, including provisioning, supporting, regulating and cultural services. The quality and quantity of these services are affected by the human beings resource use decisions (Jack *et al.*, 2008). The ecosystem service framework is widely used for studying the interdependence of agroecosystems and environment (Gómez-Baggethun *et al.*, 2010). Agroecosystems occupy approximately 50% of the earth's land surface (Smith *et al.*, 2007c; Stallman, 2011) and provide a range of services and disservices (soil erosion, sedimentation of wetlands, greenhouse gas emissions) (Kragt and Roberston, 2012). Conversion of natural land to agricultural systems and the associated management activities has impact on the non-provisioning services provided by agricultural land. Climate regulation is one such service, which is of global importance. Agroecosystems contribute towards climate change, both positively through services (carbon sequestration) and negatively through disservices (greenhouse gas (GHG) emission). Although agriculture accounts for 10-14% of total global GHG emissions (Smith *et al.*, 2007c), it also has the potential to contribute towards the mitigation of these emissions. International agreements have been agreed upon linked to the United Nations Framework Convention on Climate Change (UNFCCC). Developed countries have a commitment as part of Kyoto Protocol to reduce their carbon emissions, hence, UK under the Climate Change Act 2008, has committed to an 80% reduction in baseline (1990) emissions by 2050. Under article 3.4 of the Kyoto Protocol improved agricultural activities, land use change, and forestry that are able to mitigate carbon emissions can be included in the emission reductions targets (Smith *et al.*, 2000). These reductions in agroecosystems can be achieved through the adoption of several measures involving generation and use of renewable energy, enhancing carbon storage in soil and biomass, reducing emissions from land management activities such as reducing the use of fertilizers, reducing intensive soil disturbance due to tillage, adopting extensive grazing etc. (Smith *et al.*, 2008).

Policies are increasingly perceived as means for enhancing (reducing) the supply of environmental public goods (bads) associated with agricultural activities through recognising the value associated with non-marketed ecosystem services (e.g. climate regulation) (Sauer and Wossink, 2010). Several policy instruments have been deployed to help maintain the balance of ES provided by agroecosystems. Farmers usually have no motivation/incentives to produce non-marketed ES; therefore, external incentives can play an important role in attracting farmers towards the adoption of farm practices for the provision of such ES (Swinton *et al.*, 2007). Hence, many agricultural policies are focusing on paying farmers for conservation and protection. Among these policies, payments for ecosystem services (PES) are increasingly promoted as potentially effective tools in compensating farmers for the preservation and provision of ecosystems and their ES (Engel *et al.*, 2008; Pagiola, 2008; Wunder *et al.*, 2008).

Policies can be made more effective by designing the policies in an efficient way by taking preferences of farmers into consideration. Successful implementation of these policies can be determined by the rate of participation, characteristics of participant farms (Crabtree *et al.*, 1998) in terms of the effect achieved, and spatial characteristics (as environmental benefits are affected by location of impact).

Hence, much of the research evaluating the effectiveness of payment scheme policies explored the influence of farm/farmer characteristics, scheme attributes (Ayuk, 1997; Brotherton, 1989; Dupraz *et al.*, 2003; Espinosa-Goded *et al.*, 2010; Pagiola *et al.*, 2005; Ruto and Garrod, 2009; Thacher *et al.*, 1997), and spatial characteristics and variations (Broch *et al.*, 2013; Campbell *et al.*, 2009) on participation behaviour.

The significance of a comprehensive understanding of the contribution of agroecosystems towards climate change and its potential to contribute towards climate change mitigation is increasingly recognised for developing effective policies in this context (Abson *et al.*, 2013; Balderas Torres *et al.*, 2010; Dawson and Smith, 2007). Important research advances are required for informing future sustainable and effective climate policies that not only address the dynamics of climate change with land use changes and management but also explore the farmers' behaviour for their possible contribution in achieving climate mitigation. Although this understanding of the underlying preferences of farmers can provide sufficient information for policy design, an evaluation of costs associated with the policies can help to target the schemes more effectively. As most of the PES schemes are required to be implemented in a way that achieves maximum benefit with least cost (Chen *et al.*, 2010).

This PhD thesis evaluates the potential contribution of UK agroecosystems towards the UK's climate change mitigation targets by examining the scope of developing payment scheme policies. Overall this research study aims to contribute to the understanding of how agroecosystems can contribute towards UK's climate change mitigation targets and how this can be achieved by designing payments for ecosystem services schemes. It seeks to examine the changes in climate regulatory service provided by farmlands[1] and explore the farmers' preferences for participation in potential PES schemes. This thesis attempts to explore the heterogeneity in participation behaviour of farmers taking all three factors; farm/farmer characteristics, scheme attributes, and spatial variability into consideration for two potential payment schemes, respectively for enhancing services (carbon sequestration) and reducing disservices (GHG emissions mitigation) from farmlands. The analysis entails an assessment of regulatory service provided by UK farmlands, and the effect of land use change and farm management activities on this service, which was done as part of the UK National Ecosystem Assessment (UKNEA) project. The thesis then provides an assessment of the potential

[1] The term 'farmland' represents a farm as a whole and therefore, is used alternatively for 'agroecosystem' throughout the thesis.

participation behaviour of UK farmers in the proposed hypothetical schemes focusing on the major land use landscapes of the UK. In particular the thesis tackles the evaluation of the cost-effectiveness of the proposed schemes by providing carbon valuation for the emissions abated in accordance with the land use changes proposed by each scheme.

1.2. The Thesis plan

The remainder of the thesis is set out as follows:

Chapter 2 reviews the background literature informing the research study. It presents the necessary background of ES and the ES provided by agroecosystem, especially focusing on climate regulation service. It then introduces the policy instruments employed for conservation of ES and Payments for Ecosystem Services (PES) schemes in particular. The chapter ends with presenting the thesis motivations and specific research objectives of the study.

Chapter 3 provides the methodological framework of the research study, which is then followed by the description and the theoretical background of the methodological approaches employed for achieving the specific objectives of each stage of the thesis.

Chapter 4 presents the quantification of the changes in the climate regulation service of UK farmlands. This analysis provides estimations of the contribution of farmlands towards GHG emissions, in terms of both the potential carbon stocks and the annual GHG flows modelled with land use changes.

Chapter 5 & 6 These chapters respectively include the Choice Experiment (CE) study designed to determine the heterogeneity of farmers' preferences for participation in a GHG mitigation and carbon sequestration payment policy scheme. Each chapter includes the description of the design of the policy scheme, its attributes and levels (however, the experimental design of the CE and the questionnaire design are presented in Appendix A), followed by the estimation results from three logit models (Conditional logit, Random Parameters and Latent class models). The chapters explore the main factors affecting the behaviour of the farmers and the individual willingness to accept estimates and their distribution across the study sample.

Chapter 7 presents a cost-effectiveness study of both the potential payments schemes designed for the CE study. The chapter provides an account of carbon abatement costs for land use and management changes proposed by the two schemes. This is followed by an investigation of the spatial patterns of the carbon values across UK using GIS and regression analysis.

Chapter 8 synthesises the research study highlighting and discussing the key analytical approaches and the research contributions and limitations of the thesis. This is followed by a discussion of policy recommendations and directions for future research needs in PES scheme designs and climate regulation service.

Chapter 2 Research context

2.1. Introduction

This chapter provides an overview of the core literature that has informed the aims and motivations of this thesis. The chapter provides a brief overview of ecosystem services; specifically it discusses services provided by agricultural ecosystems – with an emphasis on climate regulation service. It also introduces payments for ecosystem services schemes, their design for agricultural ecosystems, and farmers' participation behaviour in such schemes. In-depth and more specific literature pertaining to the context, approaches and findings of each component is included in individual chapters of the thesis.

2.2. Ecosystem services and agriculture

This section presents an overview and discussion about ecosystem services (hereafter ES), especially on how this concept started. It focuses on the ES provided by agriculture.

2.2.1. Ecosystem Services

Ecosystems are life support systems, which provide renewable resources and ecological services (Costanza *et al.*, 1997). The concept of ecosystem was first introduced by Marsh in 1864 and was officially used by Tansley (Willis, 1997). This term is used to express the interdependence of species on each other and the environment (MEA, 2005). According to De Groot *et al.* (2002) these systems provide functions which are beneficial to humans through their structures and processes. Westman (1977) termed the social benefits that ecosystems provide us as *nature's services* which now are popularly termed as 'ecosystem services' (Fisher *et al.*, 2009). ES have been defined in various ways in the literature; Costanza *et al.* (1997) defined them as the *benefits human populations derive, directly or indirectly, from the ecosystem functions*. These services have also been termed as a function of complex interactions among the species and their abiotic environment (Fisher *et al.*, 2009). They maintain biodiversity and the production of ecosystem goods, such as timber, biomass fuels, natural fibres, forage, etc. ES are perceived to support and protect human well-being and include maintenance of the composition of the atmosphere, stability of climate, flood controls, waste assimilation, nutrient recycling, soil production, provision of food, pollination of crops, maintenance of species, landscapes, recreational sites, aesthetics, and amenity values (Costanza *et al.*, 1997).

ES have been defined by the Millennium Ecosystem Assessment (hereafter MEA) as; "the benefits that humans obtain from ecosystems, and they are produced by interactions within the ecosystem…" These include provisioning, regulating, and cultural services that directly affect people. They also include supporting services needed to maintain all other services. This report also classified these services as; *supporting services* (soil formation, nutrient cycling, primary production), *provisioning services* (provision of food, fuel, fibre, fresh water), *regulating services* (purification of air and water, mitigation of floods and droughts, detoxification, renewal of soil and soil fertility, control of potential pests, maintenance of biodiversity, and climate regulation), and *cultural services* (aesthetics, recreation, ecotourism, spiritual and religious values).

However, Boyd and Banzhaf (2006) argued that such a broad definition considers ecosystem products, functions, and benefits all together and is not very helpful from an economic perspective. The authors emphasise that ecosystem services and functions are two distinct entities. The functions have been defined as the flows that connect the different constituent parts of ecosystems while services are flows which have direct and immediate benefits to human i.e. are directly consumed for human well-being (Banzahf and Boyd, 2005; Boyd and Banzhaf, 2006). Considering these definitions, focusing on end-products only, some services can no longer be considered as services, such as climate regulation (carbon sequestration), rather they are considered as intermediates in services which are directly used by humans

(Kroeger and Casey, 2007). Under the influence of such definitions these services are likely to lose their importance. Hence, in agreement with Boyd and Banzhaf, Fisher *et al.* (2009) considered that services and benefits are different, and functions and process can be considered as ecosystem services as long as there are human beneficiaries. However, they disagree with the consideration of direct end-points as ES only and argue that as long as these functions and processes affect human welfare, they can be considered as ecosystem services.

This provides a more flexible approach for valuation and other assessment studies for ecosystem services by broadening the services to both intermediate functions/processes and final products.

2.2.2. Agriculture and Ecosystem services

In a simple and traditional, description agricultural land is described as land that is utilised for food crop production. In the broad sense, IPCC, (special report on LULUCF, 2000) have defined it as 'land that can provide direct benefits to mankind through the production of food, fibre, forage and fodder, biofuel, meat, hides, skins, and timber'. Thus, agricultural land includes croplands, managed grasslands, agro-forestry and bioenergy crops (Smith *et al.*, 2007c).

Agricultural land constitutes about 40-50% of the Earth's land surface (Smith *et al.*, 2007c; Stallman, 2011). Agricultural activities have been carried out for ages and have been an important tradition in most parts of the world and therefore, are considered as a separate ecosystem (MEA, 2005). Agricultural ecosystems (referred to as agroecosystems hereafter) are directly managed by humans. Apart from the primary services like the provision of food, fibre, and fuel, agroecosystems also have the capacity to provide regulating services such as regulating pollinations, pests, levels of soils loss, water supply, carbon storage and greenhouse gas emissions. Cultural services provided include the preservation of rural lifestyle, providing open-space, and rural landscapes for tourists etc. (Swinton *et al.*, 2007).

However, agroecosystems also receive ES from other ecosystems. Services such as pollination, genetic diversity, soil provision, pest regulation, water provision are provided to the agroecosystems by neighbouring ecosystems, while on the other hand, agroecosystems also provide both services (e.g. carbon sequestration, soil fertility, reducing soil degradation) and disservices (e.g. water pollution, odour, greenhouse gas emissions) to the surrounding environment. Dale and Polasky (2007) identified the interaction of agriculture with ecosystems in three forms; first, agriculture provides ES; second, agroecosystems require ES from surrounding ecosystems; and third, agroecosystems affect the quality and quantity of ES provided by other ecosystems (both positively and negatively). This linkage between the services and disservices from agriculture has been nicely illustrated diagrammatically (Figure 2.1) by (Swinton *et al.*, 2007).

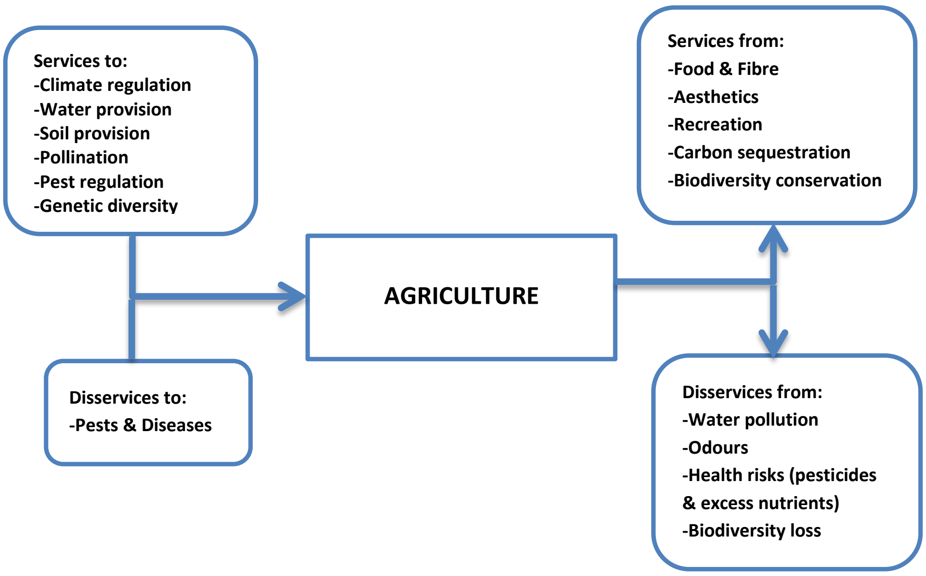

Figure 2.1 Illustration of services and disservices to and from agriculture (adapted from Swinton *et al.*, 2007)

Traditionally, most of the focus has been on enhancing production from agroecosystems and land managers have mostly concentrated on the provision of food and fibre. This has been mostly at the expense of other ES. However, there is a potential for enhancing the impact of agroecosystems on ES provision by focusing on sustainable use of agricultural land. The ES generated by agriculture are beneficial not only locally but globally and climate regulation is one of these important global services.

2.3. Climate regulation and agriculture

Agriculture influences the global climate through the storage of carbon and also through the release of greenhouse gases like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Carbon is stored in vegetation, in soil, in decomposing organic matter, and is exchanged into the atmosphere through respiration and photosynthesis (Erb, 2004). Nonetheless, stored carbon is not retained in these systems forever as human and natural activities cause it to be released back into the atmosphere. The carbon emissions from agricultural ecosystems occur in several ways including the use of fossil fuels in farm machinery, use of fertilizers (indirectly as energy is used in their production), cultivation or tillage of soils (Pretty and Ball, 2001a), which results in the removal of the topsoil and breakup of aggregates which tend to capture carbon in the soil. Carbon sequestration can be attributed to the increased soil organic matter decomposition rates due to cultivation and the loss of topsoil layer due to erosion. Developments in farm mechanisation have increased the rapid loss of the soil carbon stocks. Carbon losses from grasslands can be attributed to the intensity of grazing by livestock. This carbon is lost into the atmosphere as a vegetative loss as well as methane emissions from the livestock, both from manure and enteric fermentation (Dawson and Smith, 2007).

Global efforts have been made to combat climate change in the form of international frameworks and agreements (e.g. UNFCCC[2], Kyoto Protocol). These international agreements provide environmental benefits by making the signatory countries responsible for their actions (Dumanski, 2004). Agreements like the Kyoto Protocol bind the countries to meet their emission reduction targets by 2012[3]. These reductions can be achieved by focusing on the sources, sinks of the greenhouse gases. The Kyoto Protocol recognises the need to address the industrial and the transport sector and the land-use sector (which includes forestry and agriculture) under articles 3.4.

Land use change has been highlighted as a key human-induced effect on ecosystems (Turner *et al.*, 2003). Land use changes can cause disturbances in the ecosystems and thus affect the carbon stocks and fluxes: e.g. conversion of forest to agricultural ecosystems also affects soil organic carbon concentrations apart from the carbon lost from the trees cut down during this change. Changes in land cover and land use result in the removal or emission of carbon dioxide into the atmosphere and altering the earth's surface albedo which affects the Earth's radiation balance. They also modify the balance in the distribution of energy by disturbing the balance between the latent and sensible heat flux and thus, we can say that these land use and land cover changes alter the climate at local, regional, and even global level (Marland *et al.*, 2003). The most important land-use changes that affect the carbon sequestration property are the changes in the forest woody biomass through cutting down the trees for commercial or fuel wood purposes, production or use of woody commodities or by planting trees in different non-forested areas, conversion of forests and grasslands for agriculture or grazing

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[2] UNFCCC stands for United Nation Framework Convention on Climate Change

[3] Annex I (developed) countries according to the Kyoto Protocol are required to report the extent to which they have met their emission reduction targets for the first commitment period 2008-2012. It will then continue for the following commitment time periods.

purposes, changes in the soil of an area by carrying out ploughing and other tillage activities.

Agricultural systems contribute to carbon emissions through several mechanisms, such as: clearing of forests to create new croplands, direct use of fossil fuels for operating farm machinery; cultivation of soils resulting in the loss of soil organic matter (SOM); and indirect use of energy for the manufacture of different products (e.g. fertilizers) used in agriculture (Niles *et al.*, 2002; Pretty *et al.*, 2002).

These greenhouse gas emissions from agriculture represent approximately 10-14% of global and 8% of the UK emissions (Smith *et al.*, 2007c). These emissions include three main gases methane, nitrous oxide and carbon dioxide. Under the Climate Change Act, 2008, the UK government is committed to reduce national emissions by 80% of 1990 levels by 2050 (Moran *et al.*, 2010), with all significant sources coming under scrutiny. The need to achieve reduction in greenhouse gas emissions in an economically efficient way is recognized by the Committee on Climate Change (CCC). Mitigation from agricultural activities also needs to be addressed in the same way by recognizing and implementing the mitigation measures which can be enacted at a lower (Moran *et al.*, 2010; Smith *et al.*, 2000) or least cost. Some of the abatement options can not only result in lower emissions but can also deliver improved profitability and thus might be adopted without any specific intervention. The measures can be categorized as: *Reducing emissions* of greenhouse gases (CO_2, N_2O and CH_4), which are released to the atmosphere in large amounts, by managing the flows of carbon and nitrogen more efficiently; *enhancing removals* by increasing the storage of carbon (carbon sequestration) in both soil and vegetation through improvements in management practices, which helps in withdrawing CO_2 from the atmosphere and in some instances CH_4 can be removed from the atmosphere as well; *avoiding emissions* by using bio-fuels from crops or agricultural residues. A vast literature is available discussing and presenting the mitigation measures that can be carried out in order to reduce the emissions or manage or improve the sinks from agricultural ecosystems (Lal, 2008; Moran *et al.*, 2010; Paustian *et al.*, 1997; Smith *et al.*, 2008; Smith *et al.*, 2000).

2.4. Policy instruments for conservation of ecosystem services

Humans, directly or indirectly, depend on the products and services provided by ecosystems. Ecosystems are being increasingly degraded throughout the world. This degradation is resulting in the loss of or reduction in the provision of valuable ecosystem services. One of the key factors of natural ecosystem degradation and ecosystem service loss is lack of appropriate valuation or policy design for these ecosystems and their services (Defra, 2010). This lead to an increase, towards a more appropriate representation of ecosystems in policy designs.

Certain land use activities can lead to external effects and these in economics are termed as 'externalities'. An externality can be described as a positive or negative effect of an economic activity on others (Lipper *et al.*, 2009), and is not taken into account in an unregulated market. In order to overcome this economists have proposed to use taxes for negative externalities and subsidies for positive externalities (Jack *et al.*, 2008; Panayotou, 1994). Additionally, environmental policy instruments have been developed to deal with such externalities. Some examples of such policies include: command and control (direct regulation); market-based compulsory instruments (taxes, charges, and tradable permits); and market-based voluntary instruments (subsidies) (Panayotou, 1994; Zandersen *et al.*, 2009). According to Gómez-Baggethun *et al.* (2010), ES started to be included into policy structures by the early 2000s through the "Ecosystem Approach" adopted by UNEP-CBD in 2000. Later with the MEA, the ES concepts and policies around that approach have multiplied (Fisher *et al.*, 2009). With the increasing interest towards ES research, work towards the development of incentives for conservation of these services was also augmented. Economic and market based instruments were developed for pollution mitigation and conservation (Maynard and Paquin, 2004). Two main instruments in this context have been Markets for Ecosystem Services (Bayon, 2004) and Payments for Ecosystem Services (Wunder, 2005). Markets for ES include energy taxes, wetland mitigation banking in the US (Robertson, 2004), carbon markets-emissions trading of greenhouse gases in the UK (Bayon, 2004), Chicago Climate Exchange, a private trading system to buy carbon credits, and the EU emission trading system for greenhouse gas emissions (European Climate Exchange, 2008 as cited in Gómez-Baggethun *et al.*, 2010). While Payments for ES (hereafter PES) is a mechanism of providing incentives to the providers of the ES. PES have been utilised to increase the flow of resources from an ecosystem but also for improving a depleted ecosystem (Rosa *et al.*, 2002).

Mitigation can be an important part of the policies designed for meeting climate change reduction targets, since agricultural land makes up a large part of the total land use, and has had major contributions towards greenhouse gas emissions and climate change. The ES provided by agriculture produce both market and non-market benefits; however, landowners usually have little or no appropriate incentive to provide the social non-market benefits, and thus they prefer to opt for market products like food and fibre.

2.5. Payments for Ecosystem services

PES is an incentive based approach for the conservation and management of ecosystems which has attracted a lot of attention in recent years. It is a fairly novel way of managing natural resources and is quite similar to targeted subsidies (Engel *et al.*, 2008; Zandersen *et al.*, 2009). It offers new ways of addressing market failures and provides a different way of solving the under-provision of a demanded ecosystem service. The PES approach is based on the Coase theorem which states "that the problem of externalities can be overcome through private negotiations between the affected parties[4]" (Zandersen *et al.*, 2009 pg.32-33).

PES schemes are a series of mechanisms that are based on the idea that resource managers who are providers of an ecosystem service should be provided with

4 Affected parties can be the governmental organizations (government-financed schemes) or the service provider and the beneficiaries of service (user-financed schemes).

compensation by the beneficiaries of the services (Engel *et al.*, 2008). PES was defined by Wunder (2005):

a) *Voluntary* transaction where
b) A well-defined *environmental service* (or land use likely to secure that service)
c) Is being bought by a *service buyer*
d) From a *service provider*
e) If and only if the service provider secures service provision.

PES schemes have been implemented at a wide variety of scales in both developed and developing countries. PES schemes can either be based on the willingness to pay (WTP) of the beneficiaries of the ecosystem service or the willingness to accept (WTA) payments of the service provider (the ecosystem manager). In private markets both of these are joined together to determine an equilibrium price (Zandersen *et al.*, 2009).

According to Rosa *et al*., (2002) PES schemes have certain common characteristics, they:

a) use economic instruments with lowest possible costs for achieving environmental targets;
b) single out environment service;
c) prefer large scale ecosystems preferably owned by few people to reduce transaction and monitoring costs; and
d) Seek to secure private property rights and to reward landowners.

However, when designing PES schemes it is important to understand the land use and the ES provided by it and their values. This requires the recognition of the goods and services as assets that can then be traded at an agreed price (Smith *et al.*, 2006). It is also important to identify the beneficiaries and the providers, which can either be the actual users of the ES, or others such as government agencies, conservation institutions, or international funding institutions (Engel *et al.*, 2008). Wunder *et al.* (2008) also identified some issues that need to be considered while designing PES schemes: *compliance*, required to ensure that the PES recipients comply with their contracts; *additionality*, which arises if the change in ecosystem service could have been achieved without any payment programme; *permanence*, which determines whether the ES provided are long term or not; and *leakage*, which considers whether the environmentally-damaging land uses that the PES programme are replacing are being displaced elsewhere (more relevant for global scale services).

Payment programmes have attracted increasing interest as a mechanism to translate non-market values into real financial incentives to the local land managers for managing and providing the service (Engel *et al.*, 2008). These schemes have been popular for public services because they have been designed strategically for long term protection and conservation of ecosystems, natural resources and ES (Corbera *et al.*, 2009). The schemes usually provide payments to ecosystem managers to adopt changes in the way they use the ecosystem to generate positive externalities or reduce (mitigate) negative externalities from that ecosystem (Lipper *et al.*, 2009).

A wide variety of payment programmes have been implemented to provide ecosystem services across the globe, for example national scale programmes in Costa Rica and Mexico, agro-environmental programmes in the US and Europe (Engel *et al.*, 2008). In Ecuador a watershed conservation programme provides clean drinking water and a Forests Absorbing Carbon dioxide Emissions Forestation Programme has established carbon dioxide fixing plantations in the highland area (Kemkes *et al.*, 2010).

This thesis addresses the design of schemes in relation to mitigation of greenhouse gas emissions (negative externality) and enhancing carbon storage (ecosystem service/positive externality) through modifications in land use management in UK agriculture.

2.6. Payments for Ecosystem services in an agricultural context

Payments for ecosystem services have been promoted across the developing world to support environmental stewardship in agricultural and forest based landscapes and have been implemented through local scale projects involving private investors, NGOs, government, and resource managers (Kosoy *et al.*, 2008). They are increasingly applied across the developed world as well. There are more than 300 PES programmes implemented worldwide (Maynard and Paquin, 2004). Most of these have been set up to promote biodiversity, watershed services, carbon storage and landscape beauty (Wunder, 2005) e.g. The programme to conserve watershed forests for the Catskills and Delaware catchments in the US, Vittel and Perrier's PES for water quality improvements to reduce nitrate contamination due to agricultural intensification and for retaining forests to guarantee clean and reliable water source, the Environmental Stewardship programme in the UK for wide range of environmental outcomes, and the Conservation Reserve Programme in the US for landowners to deliver environmental benefits.

Land managers receive benefits from farmland. Intensive farming can provide them with higher agricultural productivity and increased income. However, this can lead to costs to society, as they receive the benefits from food production, but face the long term effects of soil erosion, and increased carbon and greenhouse gas emissions (these prove to be global costs). Therefore, payments by the service users can help make conservation a more attractive option for land managers as service providers. Figure 2.2 illustrates that the minimum payment to the service provider has to be equal to the benefits given up, when converting to the more socially beneficial land use practices. The maximum payment would equal the costs incurred by the public because of increased soil erosion, and carbon and greenhouse gas emissions (climate change).

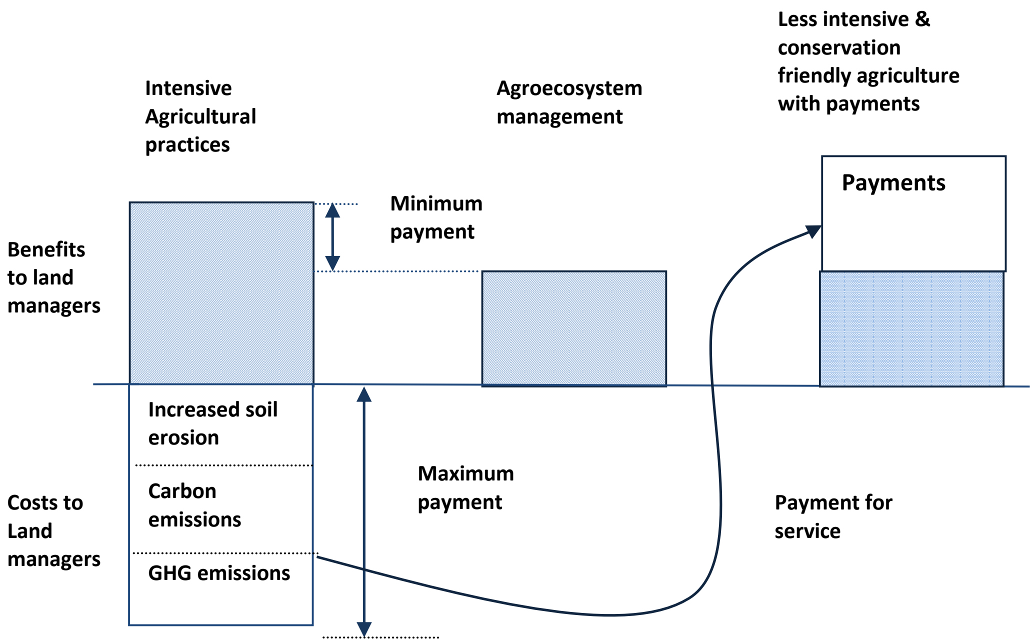

Figure 2.2 The logic of a PES scheme for agroecosystems (Adapted from Engel et al., 2008)

In the developing world context the payment schemes also have an added advantage of providing funds to the poor land owners (Rosa *et al.*, 2002 pg 11) who are providing the service by managing the ecosystems. This has resulted in more sustainable livelihoods through the provision of cash or other incentives (Pagiola *et al.*, 2005).

In the UK, payment schemes were introduced as agri-environment schemes. The UK was one of the first countries in the EU to introduce these schemes in the 1980s. These schemes paid farmers to deliver environmental benefits, such as protecting and enhancing biodiversity, landscapes and historic features, and promoting low-input farming systems. Most of these schemes have been voluntary and, therefore, depend on farmers' willingness to participate in the schemes. The development of these schemes has provided state support to farmers for making environmental improvements to their land and for changing their farming practices to protect traditional less intensive farm habitats. Some examples of such schemes include

Environmentally Sensitive Areas, the Countryside Stewardship scheme in England, Tir Gofal in Wales, the Countryside Premium Scheme followed by the Rural Stewardship scheme in Scotland, and the Countryside Management scheme in Northern Ireland (Defra, 2010). Agri-environmental schemes have been a popular means to enhance the supply of public ES associated with agricultural activities. These schemes have encouraged land managers to adopt agricultural activities that can enhance the supply of ES or mitigate the negative effects, by offering compensation payments (green payments). These schemes have been considered to be a combination of incentive based policies and command and control (Sauer and Wossink, 2010).

2.7. Overview of design and participation in PES schemes

In this context, farmers are the largest group of resource managers. They depend on and provide a wide variety of ecosystem services through their land use activities. The farmers' role can have both positive and negative effect on ecosystems and ecosystem services. Understanding their behaviour and attitude and the factors driving their decisions can be useful in designing new strategies that can enhance ES. This presupposes that the participants would at least not be worse off than without the PES programme, otherwise they would not be willing to participate (Pagiola *et al.*, 2005).

Participation in PES programmes has been voluntary and has been termed as an 'indicator' of scheme effectiveness (Wilson and Hart, 2000). Considerable research has been conducted towards the motivations behind farmers' participation looking into their preferences towards the design and scope of PES schemes.

Dupraz *et al.* (2003) found that the scheme participation will be more likely for farmers who understand the utility of the measure, either because of their education levels or positive attitude towards environment. Wunder *et al.* (2008) emphasized that farmers' participation in payment schemes is influenced not only by its contribution towards household income and land opportunity cost but also on non-monetary incentives like increase in land tenure security, improvement in internal organization, increased visibility of community for donors and organisations. Potter and Gasson (1988) conducted a study in England and Wales to estimate the extent to which agricultural land managers are likely to participate in payment schemes.

Pagiola *et al.* (2005) summarized the factors that affect the land manager's decision to participate into three groups:

a) Factors that affect the *eligibility* of the participant; this includes whether the land comes into the target area or not, whether the land follows the required management practices and whether the land is productive enough;

b) Factors that affect the *desire* to participate; the land manager or owner need to think if participating in the scheme will be profitable enough and if the current farming practices fit in the scheme or not; and

c) Factors that affect the *ability* to participate; these include security of land tenures, ability to meet the investments needed and the ability to required the needed technical assistance.

Studies, for example the ones by Ayuk (1997), Caveness and Kurtz (1993), Thacher *et al.* (1997), have indicated that farm size is positively related to the farmers' willingness to participate in payment schemes. It has also been suggested that larger land holdings, production capacity and incomes, lead to greater flexibility towards the land manager's decision to participate (Nowak, 1987). Godoy (1992) highlighted the importance of land tenures especially for long term payment schemes. Apart from these external factors a few studies (Brotherton, 1989; Potter and Gasson, 1988; Wilson, 1996) postulated that some internal factors, such as the attitude of the land owners towards the payment schemes or environmental friendly schemes, affect their participation in such schemes. Ayuk (1997) and Wilson (1996) have suggested that internal factors like land manager's age and education also influence his decision towards participation (Zbinden and Lee, 2005). These studies have also indicated that in order to ensure maximum number of eligible participants in payment schemes, policy makers should target conservation-oriented land owners.

The farmers' decision to participate in payment schemes by selecting policy alternatives other than the *status quo* can be formulated as dependent upon the maximization of its utility, subject to resource constraints. Farmers' livelihood depends upon their agricultural produce, and usually for them budget constraints include the off-farm incomes and restricted profit generated by on-farm activities (Dupraz *et al.*, 2003). This has been usually addressed by providing sufficient payments or introducing practices that are economically profitable. Generally it is assumed that farmers' decisions are based on utility maximization rather than profit. Therefore, willingness to accept (WTA) estimated can provide an insight into the profit foregone, which the land manager is willing to trade-off.

Moreover, it has also identified that spatial factors can also affect the farmers' willingness to accept. According to Campbell *et al.* (2009) the spatial distribution of the WTA estimates can help to identify the effective areas for targeting the policies. According to Bateman *et al.* (1999), rural landscapes are usually spatially spread across, therefore, the WTA estimates can vary according to the pre-dominant agricultural land use and the landscape attributes. Hence, incorporating spatial information can be useful in the design and effective implementation of ES conservation policies.

Understanding the potential participation in the payment programmes can be important to inform the policy makers for future policy decisions related to the development of payment schemes.

2.8. Thesis motivation and research objectives

Climate change and greenhouse gas emissions are important issues for agroecosystems because of their potential impacts on agricultural production and agriculture being a major contributor to the build-up of greenhouse gases into the atmosphere. Agroecosystems also have the potential to reduce these emissions and enhance the provision of climate regulation services.

Payments for Ecosystem Services (PES) schemes have become increasingly popular policy instruments for conservation and protection of ES in the agricultural sector. As explored in the review of the literature above, a number of studies have assessed the potential participation of land owners' in PES schemes by determining the factors affecting their behaviour, addressing improvements in PES scheme designs by concentrating on farmers preferences for different scheme attributes.

However, some research gaps in ecosystem service management: include appropriate estimations and of the potential to enhance the provision of ES; effective design of incentives for ES provision; and improvement of such incentives in terms of their cost-effectiveness. Another issue that has not been sufficiently addressed has been the extent to which specific geographic areas should be targeted for policy development. Detailed spatial distribution of required incentive compensation can help identify the areas of value that can be targeted more effectively. The literature review revealed that none of the currently published studies have addressed farmers' WTA requirements for climate regulation service.

Therefore, research towards effective design of PES in the agricultural sector needs to address the different dimensions of the ES provided by agroecosystems and to gain insight into the behaviour of the land managers towards the provision of those ES. This underpins the key motivation of this research study. Therefore, the current study builds on the definitions (discussed in section 2.2) of Daily (1997), MEA (2005), and Fisher and Turner (2008), which provide a more precise justification of using climate regulation service provided by agroecosystems as an ecosystem service and assessing the potential use of payments as an economic instrument to help enhance this service. The derivation of the payment estimates is important since they can help provide information to policy makers to design and implement more effective policies.

This thesis also contributed to the UK National Ecosystem Assessment (UKNEA) report. It estimated changes in the climate regulatory service provided by UK enclosed farmlands in terms of carbon and greenhouse gas stocks and flows. The thesis assesses the scope of provision of climate regulation service by farmlands in the UK through the design of policy incentives.

Three main research objectives are defined for this thesis to achieve the overall aim of investigating the design of PES for climate regulation service provided by agriculture. This provides a better understanding of how the agricultural sector can contribute towards meeting the UKs' GHG emission reduction targets.

Objective 1: To explicitly model and predict changes in regulatory service provided by farmlands due to changes in land use induced by climate change.

Further sub-objectives to achieve the main objectives were:

a. To collate and review previous literature and outline an overview of the carbon stocks, both soil carbon (SOC) and vegetative carbon (biomass) stocks (BIOC), for different land uses.
b. To develop flow estimates of GHG emissions for each land use.
c. To evaluate the change in regulatory service by enclosed farmlands by estimating the potential changes in carbon stocks and GHG flows for two climate change scenarios for the year 2020, 2040, 2060.

Objective 2: To investigate land owners' payment scheme preferences for enhancing climate regulation (through emissions mitigation and carbon sequestration) and to suggest scheme design for developing effective policies for attracting farmers to contribute towards the UK's carbon abatement targets.

This was achieved by exploring the following sub-objectives:

a. Estimating farmers' willingness to accept (WTA) requirements for adoption of GHG mitigation and policies for potential reduction in GHG emissions from UK farmlands.

b. Estimating farmers' WTA requirements for adoption of changes in land use practices through the uptake of carbon sequestration policy.

c. Exploring the extent of heterogeneity for two potential payment policies and investigating whether this heterogeneity is associated with particular farm or farmer characteristics.

Objective 3: To calculate carbon abatement costs for potential payments schemes and provide an analysis of the spatial pattern of the carbon abatement costs through PES schemes across the UK.

The sub- objectives in this context included:

a. To estimate the carbon abatement costs for the two potential policy schemes explored under objective 2, and compare the cost-effectiveness of the schemes.

b. To provide an analysis of the spatial pattern of the carbon costs through PES schemes across the UK to identify the areas of highest potential for effective implementation of policies.

This thesis uses multiple methodological approaches to address the objectives and sub-objectives. The next chapter provides a detail description of the methodological framework and approaches employed to achieve the specific research objectives of the study.

Chapter 3 The Research framework and Methods

3.1. Introduction

This chapter provides an overview of the approaches employed for the different analytical components of the thesis. The chapter describes the overall research framework in terms of stages and the steps taken to achieve the specified objectives of the research. It also provides an elaborate description of each method employed for each stage of the analysis, while the data and individual steps of the analysis are provided in the respective results chapters.

3.2. Research framework

Land use management activities impact the climate regulation service provided by agroecosystems by moderating global GHG emissions. On the other hand agricultural land use is also affected by the changing climate. Understanding the current balance of carbon inputs and greenhouse gas emissions due to land use change and land management activities, and the impact of these emissions on agriculture itself, is crucial in predicting the impacts of future land use change on the climate regulation service provided by farmlands. This is also important for the design and effective implementation of efficient policies to enhance the climate regulation service provided by agriculture.

This thesis aims to investigate the design of PES for climate regulation services provided by agriculture in order to provide a better understanding of how the UK farmlands can contribute towards the UK’s emissions reduction targets. The research was split into three main analytical components to achieve the three main research objectives. The first part aims to quantify the climate regulatory service provided by UK farmlands. This helps to identify the changes in the climate regulatory service provided by farmlands in terms of GHG emissions and carbon sequestration due to changes in land use and management activities. This informs the analysis of how to design policies to mitigate climate change. The second part aims to evaluate potential PES scheme designs for enhancing the climate regulation service provided by farmlands. The third part uses parts one and two to develop a carbon abatement cost analysis for potential PES schemes and identify the spatial distribution of the costs of mitigating carbon emissions and enhancing sequestration, and link the costs to the landscape and socioeconomic attributes of the farms and farmers. This spatial analysis will identify the areas of lower carbon value in terms of achieving climate change mitigation cost effectively in PES schemes.

The three stages follow a logical interlinked pathway to examine the effective use of land use management for enhancing climate regulation incorporating farmers' decision making. Figure 3.1 provides the integration between the different stages of the analytical framework. The three stages are discussed in detail in the subsections to follow.

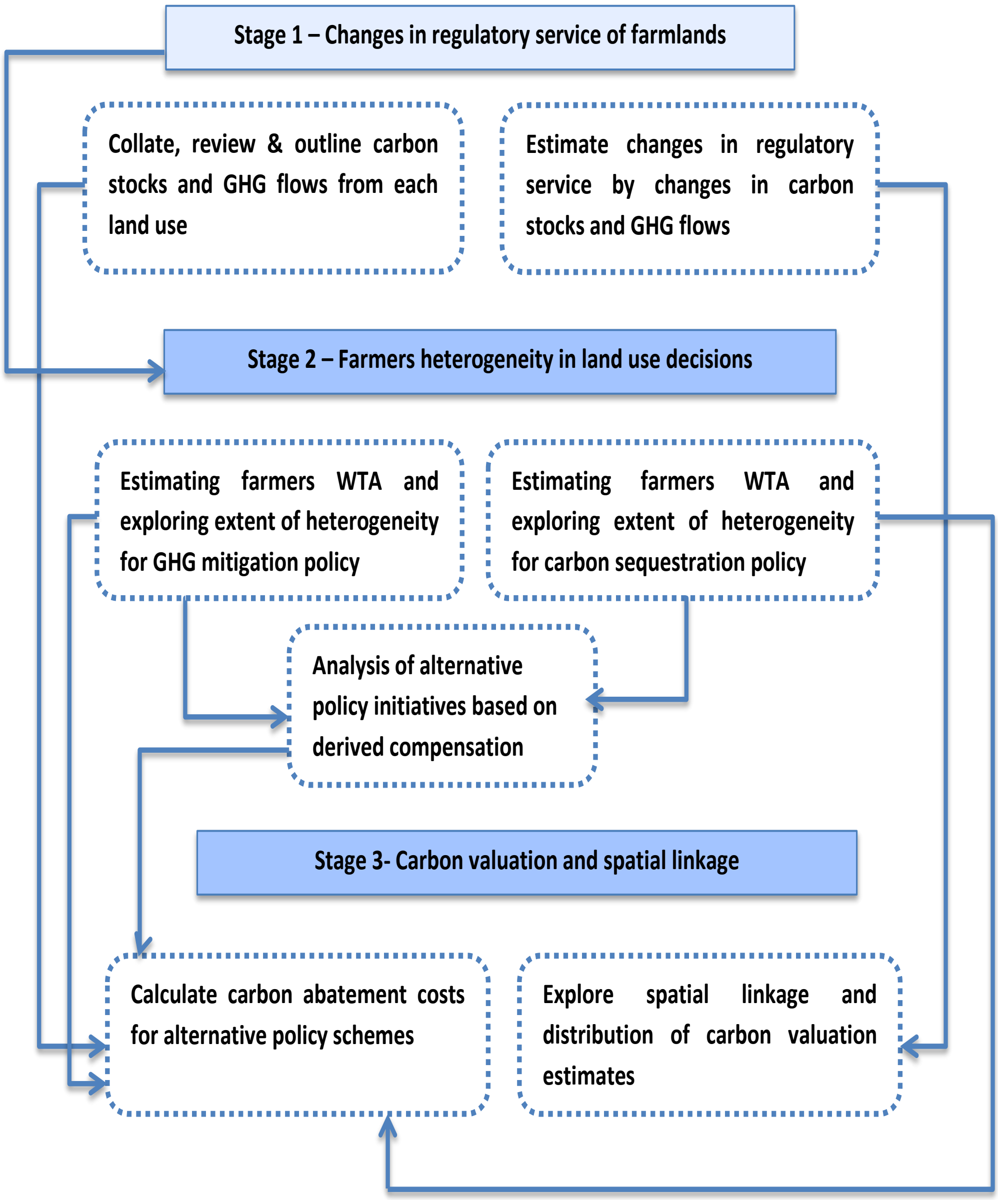

Figure 3.1 Methodological framework of the research study

3.3. Research stages and Methods

This section provides details of each empirical stage of the thesis and the methods employed to conduct the analysis of each stage.

3.3.1. Stage 1: Estimations of changes in regulatory services

The first stage of the research framework corresponds to the first objective of the thesis – **to explicitly model land use related agricultural GHG emissions under high and low UK Climate Impacts Programme (UKCIP) emissions scenarios for the period 2004-2060.** As mentioned earlier this stage proposes to provide a quantification of changes in regulatory service provided by farmlands due to changes in land use and farm management activities. This included a comprehensive study of the contribution of farmlands towards GHG emissions, from both the potential carbon stocks and annual flows, modelled with the land use changes by using outputs from a land use model and thus, exploring the changes in the GHG emissions at a national extent in the UK. This stage was conducted as part of the UK National Ecosystem Assessment (UKNEA) in collaboration with the economics team for climate regulation service assessment in 'enclosed farmland[5]' (for details please refer to http://uknea.unep-wcmc.org).

The first step towards this analysis was to define the boundaries in terms of land use and livestock types. Seven land use types were considered according to the major landscapes in the UK. The land use categories included were cereals, oilseed rape, root crops, temporary grassland, permanent grassland, rough grazing, and other land-uses (such as horticulture, on-farm woodland, and bare/fallow land). The livestock types included were sheep, cattle (beef), and dairy cows. The analysis was carried out for three GHGs carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The second step was to carry out a comprehensive review of the literature to

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[5] Enclosed farmlands includes cropped and grasslands along with hedges, ditches and, small farm woodlands. Enclosed farmland is mainly managed for food production; however, they also provide landscape characters, habitats for wildlife, and recreational opportunities.

collate the data for the carbon stocks in agricultural soils and vegetation (Bateman and Lovett, 2000; Bradley *et al.*, 2005; Cruickshank *et al.*, 1998; Dale, 1997; Dawson and Smith, 2007; Milne *et al.*, 2007); carbon flows from soils and emissions from farming activities (Falloon *et al.*, 2004; Foley *et al.*, 2005; Lal, 2004; UKAgriculture, 2013; Worrall *et al.*, 2009); and GHG emissions from land uses and livestock (Beaton, 2006; Lal, 2004; Roulet *et al.*, 2007; Thomson *et al.*, 2007; UKCIP, 2009). This data was used to calculate the soil and vegetative carbon stocks, GHG emissions from land use management activities, and changes in land uses and livestock for the baseline year (2004). The third step was to predict land use change across the UK, considering selected UKCIP climate change scenarios (2020, 2040, and 2060). A structural land use model (LUM-FB) developed by Fezzi and Bateman (2011) was used to evaluate the changes in the carbon storage capacity and changes in GHG flux derived from land use management change. GIS was employed to develop maps for changes in the land use, carbon stocks and GHG emissions, as this allows linking land use changes to climate scenarios.

To estimate the changes in regulatory service based on land use changes a fine grain spatially explicit model developed by Fezzi and Bateman (2011) was employed (for details of the significance and theoretical and econometric derivation of the model please refer to Fezzi and Bateman, 2011). This model is highly spatially explicit, being implemented on a large data panel of $2km^2$ grid. The model includes data covering the whole of the UK, including the share of each land use and livestock numbers, environmental and climatic characteristics, and policy and other drives, for the past 40 years.

The LUM-FB model (details in UKNEA, 2011; Abson et al., 2013) outputs included the predicted agricultural land use shares for each land use type and predicted livestock numbers for each $2km^2$ grid for the baseline (2004) and each analysis year (2020, 2040, and 2060) under UKCIP low and high GHG emissions scenarios. The UK climate data used in the models was taken from the spatially explicit (25km resolution) UKCIP09 climate predictions. The outputs from the application of the

UKCIP scenarios to the LUM-FB model were employed for the first phase of this thesis.

The resulting climate change induced land use changes were used to calculate the annual changes in regulatory service provided by the farmlands. This was achieved by estimating the changes in potential equilibrium carbon stocks in both the above and below ground biomass across the UK, and the changes in annual emissions (flows) of GHGs which derive from changing the agricultural management or activities resulting from those land use changes. More elaborated descriptions of the framework, data and procedures undertaken for this analytical stage are provided in Chapter 4.

3.3.2. Stage 2: Investigating farmers' preferences for PES schemes

This stage deals with the second main objective of the thesis – **to investigate land owners' payment scheme preferences for enhancing climate regulation (through emissions mitigation and carbon sequestration) and to suggest scheme design for developing effective policies for attracting farmers to contribute towards the UK's carbon abatement targets.** This stage explores if payment schemes would help in contributing towards reductions (increases) in emissions (carbon sequestration), and if they would be adopted by the farming community in the UK. This involved the use of a quantitative approach to elicit farmers' choices for two potential payment scenarios, designed for both arable and livestock farmers, by employing Choice Experiments (CE). The first step in this analytical stage was to identify the capacity of agricultural land, in terms of feasible measures for GHG mitigation and carbon storage, from a review of existing literature. Taking these measures into consideration, two suitable policy schemes were defined; one for the mitigation of GHGs from livestock manure (mitigation policy scheme), and the other for enhancing carbon storage in agricultural land (sequestration policy scheme). Defining attributes and levels are the first step for a CE study design. The attributes and levels for the above mentioned schemes were chosen according to their ability to best define each scheme (a detail of the attributes and levels of each scheme is presented in Chapters 5 & 6, while the design of CE is presented in Appendix A). After the design of the policy schemes, a survey approach was employed to gather data on farmer/ farm characteristics, and land use management activities along with the farmers' choices between proposed policy schemes. The hypothetical options were presented as two possible payment schemes. Since, the survey was designed to target both arable and livestock farms, it was required that both the schemes be presented in the same questionnaire, providing the farmers with an opportunity to choose the scheme more relevant to their farm's capacity. Logit model estimations enabled an investigation of the heterogeneity in farmers' behaviour, and allowed an analysis of the how socioeconomic factors might influence farm management decisions. The CE estimations also provided the data for estimations of the compensation requirements for participation in the scheme. This was used to calculate the carbon abatement costs for the final stage of the analysis of this thesis.

A detailed overview of the methodologies that could potentially be used for such investigations and why CE was the preferred approach and its theoretical framework is presented below:

ES valuation:

The supply of ecosystem services by farm households is associated with their willingness to accept any profit loss, which is due to the reduction in the productivity and costs associated with changes in their agricultural activities. This provides an estimate of the lowest level of compensation land owners expect from implementing management changes according to payment scheme designs. WTA estimates give information on how farmers trade off different levels of attributes against per hectare payments (Espinosa-Goded *et al.*, 2009) and can help to inform the design of payment schemes (Ruto and Garrod, 2009). Hence, many of the recent studies looking into the participation of farmers in PES schemes have used the minimum WTA approach (e.g. Broch and Vedel, 2012; Espinosa-Goded *et al.*, 2009; Kaczan *et al.*, 2011).

Various methods have been employed to investigate the farmers' preferences towards scheme attributes. The two major approaches generally used include Stated Preference (SP) and Revealed Preference (RP) methods. RP methods are based on choices made in real markets, while SP methods involve hypothetical situations. The RP methods involve the valuation of a non-market good by studying actual behavior in a closely-related market. The two most commonly used RP methods are the 'travel cost method' and 'the hedonic pricing method' (Pearce, 2002). Auctions have also been employed as a method for collecting data in real markets for some studies; as they involve real transactions, they are considered to be closer to true willingness to pay or accept (Broch and Vedel, 2012). However, auctions are more difficult to organise as they are more time consuming and expensive as real payments need to be made (Kimenju *et al.*, 2005). Even though RP methods have the advantage of being based on actual choices made by individuals, their notable disadvantages are that the valuation is based on current or previous levels of the non-market and that the non-use values are not measured (Alpizar *et al.*, 2001). On the other hand, SP methods are less expensive and easier to conduct and, using a multi-attribute SP approach, can help to estimate attribute values that provide more detailed information regarding the trade-offs and values associated with different policy designs (Campbell *et al.*, 2009). SP methods include approaches like Contingent Valuation Methods (CVM) and Choice Experiments (CE). CVM has increased acceptance as a versatile and powerful methodology for the valuation of environmental changes and services. CVM is a direct survey approach for estimating consumer preferences for hypothetical market scenarios. Initially open-ended elicitation formats (CVM) were used (Hanley *et al.*, 2001) but later on there has been a shift towards dichotomous choice elicitations. CE, being a multi-attribute approach, presents respondents with various alternative descriptions of the goods, differentiated by their attributes and levels, and asks them to choose the most preferred. The willingness to pay or accept is then directly revealed by their choices.

CE was the preferred approach for this study because of its ability to estimate multiple changes for specific attributes of a policy scheme design, which can further provide detailed information of an individual's willingness to accept for each attribute.

CE was originally developed for application in marketing and transport studies (Louviere and Hensher, 1982) but gradually it became increasingly accepted in environmental valuation studies. Various studies have used it for estimation of the benefits of recreation (Adamowicz *et al.*, 1994; Bateman, 1996; Scarpa and Thiene, 2005), evaluation of water management (Birol and Cox, 2007; Birol *et al.*, 2006), and land management (Colombo *et al.*, 2005; Espinosa-Goded *et al.*, 2009).

Various studies have also used this method specifically in agroecosystems management and provision of ecosystem services (such as Beharry-Borg *et al.*, 2012; Broch and Vedel, 2012; Espinosa-Goded *et al.*, 2010; Ruto and Garrod, 2009; Tesfaye and Brouwer, 2012). CE is used to elicit respondents' preferences for specific attributes. The respondents have to choose one out of a given number of alternatives, and the inclusion of a cost attribute makes it possible to obtain, indirectly, respondents willingness to pay or accept estimates for the environmental good.

Three logit models are used to analyse the preferences and attitudes of the farmers. The conditional logit model (CLM) framework imposes homogenous preferences across respondents, which is considered to be a limitation as the preferences can be heterogeneous (Birol *et al.*, 2006). For identifying the preference heterogeneity the *random parameters model (RPL)* and *Latent Class model (LCM)* are used. The RPL allows the utility parameter to vary continuously over the complete population, whereas the LCM captures the heterogeneity across the population by classifying the population into classes. RPL allows explicitly for a range of attitudes within the population, identifies which attributes have significant levels of heterogeneity in preferences, and quantifies the degree of the spread of values around the mean while LCM provides further insight into the data by endogenously identifying groups of respondents who have similar preferences for particular attributes (Hynes and Hanley, 2005). Since accounting for this heterogeneity is important in a policy context (Garrod *et al.*, 2012) as the target group for a particular policy initiative may have very different socioeconomic characteristics and attitudes, implying differences in individual decision making. Hence, for the current research all three models will be estimated to provide an in-depth understanding of the heterogeneity of preferences and attitudes.

CE theoretical framework:

CE is based on Lancastrian Economic Theory of Value and Random Utility Theory. A CE model can be derived following McFadden (1974) and Train (2003).

Payment schemes are assumed to not only induce utility losses to farmers due to restricting farm management activities, but also to provide them with a monetary benefit for abiding by the scheme conditions. It can be posited that a farmer '*n*' will chose to participate in a scheme alternative '*i*' among *j* alternatives, if the net utility 'U_{ni}' from doing so, is greater than the status quo or other alternatives. The overall utility from a contract can be expressed as;

$$U_{ni} = U(X_i; Z_i) \tag{1}$$

Where U_{ni} is the utility derived from scenario *i*, X_i is a vector of the attributes that makes up the PES programme and Z_n is a vector of farmer *n* characteristics.

The utility that an individual derives from an alternative is considered to be associated with its attributes. So the utility function has a corresponding indirect utility function, V_{ni}, which has a deterministic component v_{ni} and an unobservable component, ε_{ni}, and is presented as:

$$V_{ni} = v_{ni} + \varepsilon_{ni} \tag{2}$$

In logit models it is assumed that ε_{ni} is independently and identically distributed extreme value (Train, 2003), and does not depend on underlying parameters or data.

The probability P_{ni} that farmer *n* chooses alternative *i* over alternative *j*, can be expressed as the probability that the utility associated with alternative *i* is greater than that associated with all the other alternatives, *j*:

$$P_{ni} = Prob\left(v_{ni} + \varepsilon_{ni} \geq v_{nj} + \varepsilon_{\mathrm{nj}}; \forall i \neq j \in C\right) \quad (3)$$

Conditional logit model (CLM)

First a conditional logit model (CLM) was used to estimate the influence of scheme characteristics on the likelihood of participation. A CLM is the most commonly used and simplest of all the choice models. The utility for CLM, including a constant term to capture the effect of unobserved influences exert over the selection of the 'business as usual' or 'do not want to participate' option becomes:

$$U_{ni} = ASC_{BAU}.BAU + \beta'_1 X_{1i} + \beta'_2 X_{2i} + \cdots + \beta'_k X_{ki} + \varepsilon_{ni} \quad (4)$$

The BAU is a dummy variable that takes a value of 0 if one of the hypothetical payment programmes is selected by a respondent on a particular choice card or 1 if the 'do not want to participate' option is selected.

It assumes that unobservable components are identically, independently distributed and follow a Gumbel distribution (Hensher *et al.*, 2005; Train, 2003). Therefore, the probability of selecting the alternative will be:

$$P_{ni} = \frac{\exp(\beta\prime_1 X_{1\mathrm{ni}} + \beta\prime_2 X_{2nI} + \cdots + \beta\prime_k X_{kni})}{\sum_{j=1}^{i} \exp\,(\beta\prime_1 X_{1nj} + \beta\prime_2 X_{2nj} + \cdots + \beta\prime_k X_{kni})} \quad (5)$$

Where, β_k is the utility coefficient and X_{kni} is the level of attribute *k* for alternative *i* for a farmer *n*.

Random Parameters Model (RPL)

In RPL models the error term for individual *n* and alternative *j*, ε_{ni} is assumed to be composed of two additive elements so that the utility function for *j* as perceived by farmer *n* is described as:

$$U_{ni} = \beta' X_{ni} + [\eta' X_{ni} + \varepsilon_{ni}] \quad (6)$$

Here β´ is the taste parameter and η´ is a vector of random normal terms whose distribution over individuals and alternatives depends on the underlying parameters and observed data relating to the individual *n* and alternative *i*.

The RPL model addresses the three limitations of standard logit models by allowing for random taste, i.e. 'variation, unrestricted substitution pattern, and correlation in unobserved factors' (Train, 2003 pg. 15) and explains taste variation by using explanatory variables and mixing distributions (Train, 2003).

Stated more explicitly, a RPL model is any model whose choice probabilities can be expressed in the form

$$P_{ni} = \int L_{ni}(\beta)\ f(\beta) d\beta \qquad (7)$$

Where $L_{ni}(\beta)$ is the logit probability evaluated at parameters β.

$$L_{ni}(\beta) = \frac{e^{V_{ni}(\beta)}}{\sum_{j=1}^{j} e^{V_{ni}(\beta)}} \qquad (8)$$

Where $f(\beta)$ is the density function, $V_{ni}(\beta)$ is the observed portion of the utility, which depends on the parameters β. If the utility is linear in β, then $V_{ni}(\beta) = \beta' x_{ni}$. In this case, the mixed logit probability takes its usual form:

$$P_{ni} = \int \left(\frac{e^{\beta' x_{ni}}}{\sum_i e^{\beta' x_{ni}}} \right) f(\beta)\, d\beta \qquad (9)$$

The mixed logit probability is a weighted average of the logit formula evaluated at different values of *β*, with the weights given by the density function$f(\beta)$.

The standard deviations of the *β* represent the individual's tastes and thus accommodates for the unobserved heterogeneity in the sample (Hensher and Greene, 2003).

The three issues that need consideration for RPL model estimations are; the selection of random parameters, distribution of the random parameters, and the number of points for simulation. For the RPL analysis in Chapters 5 and 6 the random parameters were selected by first assuming that all parameters are random and then examining their standard deviations to establish the overall contribution of the additional specification of the random parameters (Hensher *et al.*, 2005).

The influence of the distributional assumptions of random parameters are determined by defining the selected random parameters as functional forms such as normal, triangular, uniform, and lognormal (Hensher and Greene, 2003). Most commonly the normal distribution is used while the lognormal distribution is used for coefficients with an explicit sign assumption such as compensation (Train, 2003). Hence, all the attributes described in Chapters 5 and 6 were specified as normal except the compensation payments.

The selection of a number of points for simulation can be conducted by methods such as Monte Carlo simulation methods, Halton method, etc. The Halton method is considered to have the ability to achieve more precise results with fewer draws (Train, 1999) and was used to determine the model stability and precision of estimates (Hensher, 2005). For the models estimated in Chapters 5 and 6, 1000 Halton draws provided stable models.

Latent Class model (LCM)

The Latent class model (LCM) captures taste heterogeneity between different classes, each latent class being unique and thus accounting for taste variation across the population. The LCM classifies the respondents into segments and predicts their choice behaviour according to the segment they belong to. The number of segments is determined endogenously by the data (Birol *et al.*, 2006). Selecting the number of classes in the model should be based on the ability to provide interpretative simplicity; statistical criteria for model fit along with analyst's judgement, are to be considered (Boxall and Adamowicz, 2002; Scarpa and Thiene, 2005; Swait, 1994).

The LCM is specified as a random utility model where farmer *n* belongs to latent class s= (1, 2,…, S). The utility function can now be expressed as:

$$\mathrm{U}_{ni|s} = \beta'_s X_{ni} + \varepsilon_{ni|s} \qquad (10)$$

Where, X_{ni} comprises of the attributes that appear in the utility functions and β'_s is a segment specific parameter vector while $\varepsilon_{ni|s}$ represents the random variation for the farmer *n*. The probability that the farmer *n* belonging to segment *s* will choose alternative *i* is given by:

$$\mathrm{P}_{ni|s} = \frac{e^{\beta' {}_s X_{ni}}}{\sum_i e^{\beta' {}_s X_{ni}}} \tag{11}$$

In order to predict an individual's membership in a segment, an unobservable latent segment membership likelihood function is used:

$$Y^*_{ns} = \Gamma'_s \mathrm{Z}_n + \upsilon_{ns}, \mathrm{s} = 1, \ldots, \mathrm{S} \tag{12}$$

Where, Z_n denotes a vector of individual and Γ'_s is a segment specific parameter vector; and υ_{ns} is a stochastic error term. The error terms are assumed to be distributed independently across segments and individuals (Swait, 1994). The LCM then estimates joint probability to account for both choice and segment membership, $\mathbf{P}_{nis}$ **=** $\boldsymbol{P_{ni|s}}$ **.** $\mathbf{W}_{ns}$. Therefore, the marginal probability of observing farmer *n* in segment *s* choosing alternative *i* is given by:

$$P_{nis} = \sum_{s=1}^{S} \left[\frac{e^{\beta' X_{ni}}}{\sum_i e^{\beta' X_{ni}}}\right] \left[\frac{e^{\Gamma'_s Z_n}}{\sum_S e^{\Gamma'_s Z_n}}\right] \tag{13}$$

Where the probability of selecting alternative *i* is equal to the sum over all latent classes *s* of the class-specific membership model conditional on the product of class $P_{ni|s}$, and the probability of belonging to that class W_{ns} (Swait, 1994).

Marginal Willingness to Accept (WTA) estimations

The supply of ecosystem services by farm households is associated with the willingness to accept a profit loss, which is due to the reduction in productivity and cost associated with changes in agricultural activities. This provides an estimate of the lowest levels of compensation land owners expect by taking up the changes required by payment schemes. Therefore, WTA estimations enable an analysis of how farmers trade off different levels of attributes against per hectare payments.

Eliciting WTA responses helps to inform effective policies (Espinosa-Goded *et al.*, 2009; Ruto and Garrod, 2009).

WTA can be estimated by taking the ratio of an attribute's parameter coefficients to the marginal utility of the payment attribute. This provides the marginal rate of substitution between the attribute and money (Hanemann, 1994).

Individual specific conditional estimates of minimum WTA for a specific change in the particular land management attribute can be estimated using:

$$WTA_{n,k,l} = \sum_{s=1}^{S} M_{n,s} \left(\frac{-\beta'_{s,att}}{\beta'_{s,comp}}\right) \quad (14)$$

Where, $M_{n,s}$ is the estimated matrix of individual specific a *posteriori* probabilities of segment membership, and the ratio $\left(\frac{-\beta'_{k,l,s}}{\beta'_{comp,s}}\right)$ is the implicit price for the attribute change, being valued, using the parameter coefficients from the relevant latent class segment.

Welfare estimates (compensating variation)

Compensating variation (CV) is defined as the amount of money taken from income that will equate to the utility of the preferred choice after the change in quality with the utility of the preferred choice before the change (Bockstael and McConnell, 2007). The situations before and after the change needs to be compared in order to examine the monetary impact of a change. The status quo (ASC) coefficients show the marginal utility of non-participation. Subtracting the marginal utilities of all the programme attributes from the marginal utility of the status quo (ASC) can provide the overall WTA for the programme (Train, 2003). Therefore, the welfare estimates for a policy would be represented as:

$$\Delta CV = \frac{(\sum \beta_{att} - \beta_{ascBAU})}{-\beta_{comp}} \quad (15)$$

Where $\sum\beta_{att}$, is the sum of the coefficients of all the policy attributes and β_{ascBAU} is the coefficient retention of with the status quo.

ASC, the alternative specific constant, is usually incorporated into econometric analysis to capture unobservable influences beyond attributes present in the choice sets and a significant ASC indicates the presence of a status quo effect (Adamowicz *et al.*, 1998; Scarpa *et al.*, 2005). Generally in most CE studies ASC has proved to be highly significant and influences the model fit. Usually omitting the current situation would result in decreasing utility (Meyerhoff and Liebe, 2009).

The effects of the ASC on preferences and its exclusion from welfare estimations have been discussed by various studies in the literature. Reasons behind preference for the status quo include regret avoidance; maintaining consistency; misperceived costs (Samuelson and Zeckhauser, 1988); loss aversion (Kahneman *et al.*, 1991); mistrust (Adamowicz *et al.*, 1998); complexity of choices (Moon, 2004 cited in Meyerhoff and Liebe, 2009); and perceived task complexity (Meyerhoff and Liebe, 2009). However, aversion to choosing the status quo occurs if the status quo is defined in a less favourable way (Soini and Horne, 2005) through yea-saying bias to please the interviewer. Since calculating welfare measures is important for evaluation of PES schemes, the ASC is of critical importance. Alternative interpretations of ASCs are further discussed in the CE results chapters (Chapter 5 & 6) and the compensating variation estimations are described and discussed in Chapter 7.

The complete CE study design is explained in Appendix A while the framework for the analysis is presented in Chapters 5 and 6.

3.3.3. Stage 3: Carbon valuation and spatial linkage

The final stage of the research deals with the third objective of the thesis – **to calculate carbon abatement costs for potential payment schemes and provide an analysis of the spatial pattern of the carbon abatement costs through PES schemes across the UK.** This stage involves; a) calculation of carbon abatement costs by combining the individual welfare estimates from the CE study with the carbon abatement potentials, calculated from the estimated emissions/carbon storage, and b) exploring the interdependence between carbon abatement costs and the landscape and individual farms characteristics.

This stage of analysis involved estimations based on results and outputs from the first two stages of the thesis.

The carbon valuation analysis involved the estimations of emissions for each policy scheme. A Marginal Abatement Carbon Cost (MACC) was estimated by calculating the price of reductions in carbon emissions as a result of the adoption of alternative policy scenarios. This was done by defining two policy levels for each policy scheme. This helped to investigate the relationship between policy design, scheme participation and therefore the carbon reductions, and required compensation payment. The carbon abatement estimations were combined with the individual WTA estimations from stage 2 to calculate the costs per tonne of carbon.

This cost analysis was followed by a spatial analysis to provide a linkage between the carbon costs and spatial attributes. The land use maps generated in stage 1 were employed for this analysis. These spatial distributions identified the areas of lower carbon costs for climate change mitigation that can be targeted effectively by implementing PES schemes.

The spatial analysis was carried out by mapping the resulting data using GIS. The carbon values were joined with the outputs of the Business-as-usual (BAU) scenario (2004) of land use models (stage 1). Carbon abatement calculations were carried out for the BAU land use scenario according to the policy changes recommended by both mitigation and sequestration policy scheme. This helped to determine the cost-effectiveness of policy implementation in each grid (represented by the individual respondent). This provided linkage of the spatial attributes of landscape with the socioeconomic and carbon mitigation for each respondent, enabling identification of the areas with highest mitigation potential and lowest compensation costs. Regression analysis was employed to explore sources of variations in the carbon valuation. A complete description of the data manipulation, processing, and the steps of this analysis is provided in the data and methods section of Chapter 7.

3.4. Summary

This chapter provided the overall research framework of the thesis. It provided an overview of the three stages of the PhD research and how they complement each other to achieve the main aim of the study. Each analytical component was discussed in detail explaining the methods applied. The following chapters will provide, and discuss, the results of each stage individually.

Chapter 4 Estimating changes in climate regulatory service due to changes in farmland management

Abstract

Land use change is induced by various drivers such as socio-economic, technological, governance, and climate change. Agricultural systems are not only impacted by climate change but they also contribute to GHG emissions. This chapter provides estimates of changes in the GHG emissions and carbon storage in the UK farmland as a result of climate change induced land use changes. The analysis was done in two phases; first, the greenhouse gas emissions and carbon storage (for both soil and biomass carbon) stocks were calculated for different land use and soil types across the UK by reviewing existing data. Then a high resolution land use model, at the scale of the UK, was used to explicitly model land use related agricultural GHG emissions under high and low emission scenarios as defined by the UK Climate Impacts Programme (UKCIP), for the period from 2004-2060. The analysis showed that there are large variations in land use change across the UK with respect to climate change scenarios. The estimates predicted significant regional differences, revealing an increase in GHG emissions in the northern and western parts of the UK and a decrease in lowland south and east of the country. The results also predicted an 11% increase in emissions over the next couple of decades considering climate change induced land use change. The analysis suggests that climate change will reduce the capacity of ecosystems to regulate the increases in carbon emissions. However, some adjustments to land use will help to reduce emissions for some regions.

4.1. Introduction

Climate change is an important issue in agriculture because it not only affects agricultural production, but also because agriculture is a major contributor towards the emission of GHGs (Paustian *et al.*, 1997). Agriculture accounts for 10-14% of global (Smith *et al.*, 2007c) and approximately 9% of the UK (Stallman, 2011) emissions of GHGs. About 70% of UK land is under agricultural production (Banzahf and Boyd, 2005). On the other hand, a climate regulation service is provided by agroecosystems in terms of accumulation of atmospheric CO_2 as carbon in soil and biomass.

Agriculture contributes to GHG emissions through the use of fossil fuels; emissions from production, transport and application of fertilizers, pesticides, herbicides; from livestock through direct release or from vegetation and soil due to grazing; and tillage of soils, which breaks up aggregates to release carbon stored in soil (Lal, 2004; Pretty and Ball, 2001a; Smith *et al.*, 2008). The major GHGs emitted include CO_2, CH_4, and N_2O. About one third of global CO_2 emissions are caused by changes in land use like forest clearing, cultivation shifting, intensive cultivation, etc. and approximately two-thirds of the global CH_4 and most of the N_2O also are released by agriculture (Kotschi and Muller-Samann, 2004).

However, agriculture simultaneously offers a potential to reduce GHG emissions significantly. Land use and management activities are an important part of climate regulation assessments (Rounsevell and Reay, 2009). Different land use activities have different capacities for storing or emitting GHGs, depending upon the intensities of changes. Agricultural land use activities are associated with energy consumption and GHG emissions, and these land uses can have a profound impact on the greenhouse gas flux. Land use changes affect the level and value of climate regulation service. It can alter the carbon stocks both below and above ground for a given land use (Erb, 2004). The impacts of land use change on agriculture, have received considerable attention (Hediger, 2006; Moran *et al.*, 2010; West and Marland, 2003). Since GHG emissions vary according to land use type (Lal, 2004), changes in land use will affect these emissions (Smith, 2004). Given that both predicted climate change patterns and the productivity of agricultural land varies across regions, changes in agricultural land uses will alter productivity, and are expected to affect the GHG emissions across space even at relatively fine spatial scales. Consequently, models for GHG estimations should ideally be spatially explicit to account for fine resolution adjustment to climate change through changes in land use and consider the impact of these land use changes on GHG emissions.

Thus, this chapter builds on the literature of estimations of GHG emissions to predict the effect of climate change on land use change decisions and its subsequent effect on the climate regulatory service provided by agriculture. The analysis uses the structural econometric model (as described in Chapter 3) to explicitly model land use related agricultural GHG emissions under high and low emission scenarios as defined by the UKCIP for the period from 2004-2060. Hence, the specific objectives of the study are:

- To collate and review previous literature and give an overview of the carbon stocks, both soil carbon (SOC) and biomass (vegetative) carbon (BIOC) stocks, for different land uses.
- To develop flow estimates of GHG emissions for each land use category.
- To evaluate the change in regulatory service by enclosed farmlands by estimating the potential changes in the carbon stocks and GHG flows for two climate change scenarios for each of the years 2020, 2040 and 2060.

The chapter starts with an overview of the analytical framework (Section 4.2). Section 4.3 provides a detailed description of the data collated for the estimations of carbon and GHG (CO_2, N_2O, and CH_4) fluxes from UK farmlands, followed by data for GHG flux estimations from agricultural land use change (Section 4.4). The results and discussions of the estimations are provided in section 4.5, while the chapter concludes at section 4.6.

4.2. Analytical framework

This analysis includes the evaluation of the change in the regulatory service of UK enclosed farmlands (defined in Chapter 3). The analysis includes *carbon stock* and *GHG flux* estimations from land use changes. The carbon stock estimates are based on predicted changes in both the SOC and BIOC under the land use patterns. The GHG flux estimates include both the GHG emissions resulting from land use change and changes in management activities (including energy usage, emissions from fertilizers and livestock, etc.) and the annual SOC emissions or storage resulting from changes in land use. All the GHG fluxes and carbon stocks are converted to CO_2 equivalents (CO_2e).

The changes in land uses are drawn from the output of the CSERGE agricultural land use model (LUM-FB) (see detailed description in Chapter 3) based on the predicted climate changes associated with the UKCIP low and high GHG emission scenarios (Baggott *et al.*, 2007) for the years 2004, 2020, 2040 and 2060 (detail below). The analysis also includes estimates of both the changes in potential equilibrium carbon stocks and the changes in annual flux of GHGs associated with the shifts in the modelled agricultural land use.

The GHGs included in the analysis are CO_2, CH_4, and N_2O. CH_4 is produced by decay of organic matter under anaerobic conditions. The enteric fermentation in ruminant livestock, stored manures and biomass burning are some of the practices which result in the production of methane (Mosier *et al.*, 1998). N_2O is released by microbial action on nitrogen in the soils and the application of organic (manure) and artificial fertilizers (Smith *et al.*, 2007b) while CO_2 is released from the soil due to soil decomposition and from land use and management activities (Lal, 2004).

The analysis included eight land use types; cereal cropping, oilseed rape, root crops (sugar beet and potatoes), temporary grassland, permanent grassland, rough grazing, and other agricultural land-use (including woodland, horticulture, and bare/fallow land). It also included three livestock types; sheep, dairy and beef. The livestock numbers and land use shares are derived from the LUMFB model. The framework of this study is presented in Figure 4.1.

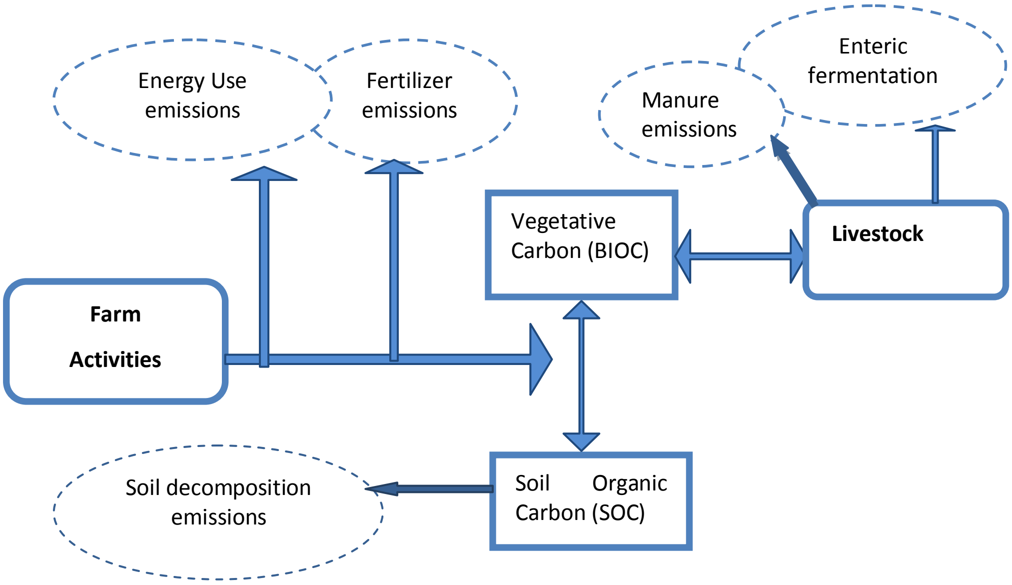

Figure 4.1 Changes in land use and associated GHG emissions and carbon stocks included in the analysis

For this analysis (Figure 4.1) it is assumed that the SOC stocks depend not only on the land use but also the soil type (either organic or non-organic), while BIOC is assumed to be dependent on land use only. As mentioned above, each land use is associated with certain farm management activities such as tillage, fertilizer spreading, pesticide spraying etc. Carbon emissions include direct emissions from soils and emissions from changes in farm management activities due to land use changes are captured. Livestock contributes to the GHG emissions through manure and enteric fermentation which release N_2O (due to excretion of nitrogen) and CH_4 respectively. The analysis does not include introduction of new crops and technological innovation in carbon efficiency.

UKCIP Scenarios

The UKCIP, in conjunction with the Met Office, has created projections for a variety of climatic variables under certain global scenarios[6] detailed by the Intergovernmental Panel on Climate Change (IPCC). The projections correspond to three future emissions scenarios – Low, Medium, and High. However, for the current study only the Low and High emissions scenarios were employed to examine the potential changes in the carbon stocks and GHG flux from UK farmlands. The year 2004 was taken as the baseline year and the projections were estimated for the years 2020, 2040 up to 2060.

4.3. Data and Estimations of carbon stocks and GHG flux from UK enclosed farmlands

Carbon stored in live biomass and the soils of agricultural systems cannot be retained permanently, as different human and natural activities cause it to be released back into the atmosphere. According to Dawson and Smith (2007) carbon emissions in farmlands occur in the form of:

i. Increased soil organic matter decomposition rates due to intensification of cultivation.
ii. Soil degradation due to erosion.

The emissions of GHGs from enclosed farmlands occur because of farming activities and livestock. The major sources of GHG were considered in the annual GHG emission flux and these include:

iii. The indirect CO_2 emissions due to energy use from agricultural activities such as tillage, sowing, spraying, harvesting, and the production, storage and transport of fertilizers and pesticides. The GHG estimates were calculated for typical farming practices for each

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6 This data is freely available from the UKCIP website (http://ukclimateprojections.defra.gov.uk)

hectare, and were applied to each land use type in order to map these emissions across the UK.

iv. Emissions of N_2O and CH_4 from livestock, including beef cattle, dairy cows and sheep through the production of manure and enteric fermentation.

v. Direct emissions of N_2O from artificial fertilizers.

In order to estimate GHG emissions for the UK it was assumed that agricultural activities can be adequately described from the typical farming practices for each crop type.

A detailed account of carbon storage and GHG fluxes from the enclosed farmlands is presented in the following sub sections:

4.3.1. Soil carbon stocks

Data:

Various studies have estimated carbon stocks across the UK under different land uses (see Bradley et al., 2005; Dawson and Smith, 2007; Milne and Brown, 1997). Soil organic carbon represents the UK's largest carbon stocks (Bradley et al., 2005; Milne et al., 2007). Soil types were defined as either organic (peat) soil or non-organic (non-peat) soils. Areas of peat soils were identified from the European Soil Database (Watkiss and others, 2005).

For organic soils it is assumed that undisturbed soils (rough grazing) had an average soil carbon content of 1200 tC/ha, (Bateman and Lovett, 2000). Dawson and Smith (2007) estimated the total soil carbon in GB to be 9.8±2.4 billion tonnes of which, 5.1 billion tonnes is stored in the peat lands. The values for non-organic soils were derived from Bradley *et al.* (2005) estimates which are: 132.6 tC/ha for England, 187.4 tC/ha for Scotland, 142.3 tC/ha for Wales and 212.2 tC/ha for Northern Ireland.

Estimations:

The ability of soil to store carbon depends on the type of soil and the land use applied to those soils along with the related climate, hydrology, and topography of the area (Abson *et al.*, 2010). For this analysis the two factors, i.e. soil type and land use, were modelled.

The influence of land use on the two soil types was accounted for by applying land use factors to the national SOC estimates. Taking data from Cruickshank *et al.* (1998) it was assumed that non-organic soils under arable land uses have 84% of the SOC of the same soils under improved grassland, while soils under woodland and rough grazing have 33% more than improved grasslands.

Peat soils under arable land uses were assumed to have long term equilibrium SOC equal to the average non organic soil SOC of the region within which the soils are located. For peat soils under temporary grasslands, permanent grasslands and woodlands; SOC was assumed to be 580 tC/ha (Cruickshank *et al.*, 1998).

The validity of the model assumptions for the estimates of potential equilibrium SOC for the UK for the baseline year (2004) was checked by comparison with the most comprehensive estimate of UK SOC provided by Bradley *et al.* (2005). They estimated the UK SOC stock as 4,563 million tC, the estimates for the baseline year scenario (2004) for the current study were 4,616 million tC, showing a discrepancy of 1.3%. The largest discrepancy was 5.8% for Scotland, which is potentially due to the extensive peat soils found in Scotland and the difficulty in accurately estimating SOC in peat soils due to issues like surrounding soil depths along with associated technical factors (Pretty and Ball, 2001b). The estimates of average equilibrium SOC for each land use are presented in Table 4.1.

Table 4.1 Average SOC estimations for different land uses and soil types in the UK

Land uses	England		Scotland		Wales		Northern Ireland	
	Non peat (tC/ha)	Peat (tC/ha)	Non peat (tC/ha)	Peat (tC/ha)	Non peat (tC/ha)	Peat (tC/ha)	Non peat (tC/ha)	Peat (tC/ha)
Oilseed rape	111	133	157	187	120	142	178	212
Cereals	111	133	157	187	120	142	178	212
Root crops	111	133	157	187	120	142	178	212
EFH_other	111	133	157	187	120	142	178	212
Temporary grassland	133	580	187	580	142	212	212	580
Permanent grassland	133	580	187	580	142	212	212	580
Rough grazing	176	1200	249	1200	189	282	282	1200
Woodland	176	580	249	580	189	282	282	580

4.3.2. Estimations of biomass carbon stocks

Data:

The data for estimates of the biomass carbon stocks for different agricultural land uses were taken from Cruickshank *et al.* (1998); Milne *et al.* (2001); Bradley *et al.* (2005); and Ostle *et al.* (2009). It was assumed that annual vegetative carbon stock represents a permanent stock while a particular agricultural land use continues. The biomass lost through harvest in one year is assumed to be replaced by new biomass growth in the next year.

Estimates:

The vegetative carbon stocks were based on both above and below ground biomass. For the baseline year it was estimated that the total UK BIOC stocks were 28.82 million tC. This is in broad agreement with the findings of Milne *et al.* (2001) who estimated vegetative carbon stocks of 22.8±5.1 million TC for Great Britain (England, Wales, and Scotland only). Table 4.2 indicates the per hectare estimates of BIOC for various land uses considered in this analysis.

Table 4.2 Average vegetative stocks for different land uses

Land use	**BIOC (tC/ha)**
Oil seed rape	1.8
Cereals	2.4
Root crops	2.5
Temporary grasslands*	0.9
Permanent grasslands*	0.9
Rough grazing (non-organic soils)**	1.66
Rough grazing (organic soils)**	2.0
Other	1.4
Woodland	36.8

**Based on improved grassland category ** Based on semi-natural grassland category*

(Sources: Cruickshank et al., 1998; Milne et al., 2001; Ostle et al., 2009; Bradley et al., 2005)

4.3.3. Estimations of direct CO_2 emissions from soils

The emissions from soils (Table 4.3) include emissions from peat soils which release CO_2 under aerobic conditions. For all other kinds of soils (mineral soils) the soil carbon flux is assumed to be zero at equilibrium (Falloon *et al.*, 2004).

Table 4.3 Direct carbon emissions from soils

Land uses	Soil emissions ($tCO_2eq/ha/yr$)
Cereals	15
Oilseed rape	15
Root crops	15
Temporary grassland*	7.30
Permanent grassland*	7.30
Rough grazing (non-oragnic soils)**	0
Rough grazing (organic soils)**	0
Other	11.15

**Based on improved grassland category ** Based on semi-natural grassland category*

(Sources: Baggot *et al.,* 2007; IPCC, 2006)

4.3.4. Estimations of indirect CO_2 emissions

The carbon flows are an integral part of the carbon consequences in the enclosed farmlands sector, and these emissions are attributed to the different management practices associated with different land uses.

Data:

The carbon emissions (Table 4.4) for this analysis were calculated for agricultural activities such as tillage, sowing, fertilizers and pesticides (herbicides, fungicides, insecticides) applications, harvesting and bailing by combining the estimates from Lal (2004), which is based on a review of existing studies converted into tCO_2e/ha.

Estimations:

The analysis was carried out for the eight land use types mentioned in the framework section. The emissions were based on typical farming practices, which have been taken from the UK agriculture website (Chen *et al.*, 2010). The farming practices for each land use type are as follows:

Cereals: A typical production cycle for cereals includes onetime conventional tillage (including mouldboard ploughing, two discings, field cultivation and rotary hoeing) emitting 0.13tCO_2e/ha/yr, one time sowing emitting 0.01tCO_2e/ha/yr, 2 fertilizer sprays emitting 0.24tCO_2e/ha/yr, 2 pesticides (herbicides and insecticides) applications emitting 0.01tCO_2e/ha/yr, one time combine harvesting emitting 0.0366tCO_2e/ha/yr, and one bailing emitting 0.12tCO_2e/ha/yr.

Oilseed rape: A typical production cycle for oilseed rape includes a conventional tillage emitting 0.13tCO_2e/ha/yr, sowing emitting 0.01tCO_2e/ha/yr, 3 fertilizer sprays emitting 0.27tCO_2e/ha/yr (fulfilling N requirement is 210 Kg N/ha), 5 applications of pesticides (2 herbicides, 2 insecticides, and 1 fungicide) emitting 0.03tCO_2e/ha/yr, and combine harvesting emitting 0.0366tCO_2e/ha/yr.

Root crops: root crops also involve conventional tillage emitting 0.13tCO_2e/ha/yr, sowing emitting 0.01tCO_2e/ha/yr, fertilizer spraying emitting 0.26tCO_2e/ha/yr (N requirement 200Kg N/ha), 4 pesticide applications (including 3 insecticide spraying and 1 herbicide) emitting 0.02tCO_2e/ha/yr, and harvesting emitting 0.0366tCO_2e/ha/yr.

Temporary grasslands: includes conventional tillage, which is assumed to occur only once in every four years, emitting 0.03tCO_2e/ha/yr, sowing also is assumed to be once in four years therefore emitting 0.003tCO_2e/ha/yr, fertilizer application emitting 0.33tCO_2e/ha/yr, forage harvesting emitting 0.0011tCO_2e/ha/yr, and bailing emitting 0.121tCO_2e/ha/yr. Here, the distinction between dairy and beef grasslands has been based on the nitrogen (fertilizer) requirement for each use of the grasslands which, for temporary grasslands with beef cattle, is 175 KgN/ha, and for dairy cows it is 250 KgN/ha.

Permanent grasslands: include only 1 fertilizer application emitting 0.23tCO_2e/ha/yr (N requirement is 175 KgN/ha/yr), and bailing emitting 0.121tCO_2e/ha/yr.

Combining the number of applications and the emissions from each farming activity provides us with total indirect emissions for each land use, which are summarised in Table 4.4.

Table 4.4: Indirect carbon emissions for each land use specifically for each agricultural activity.

Land use	**Emissions from each farm activity ($tCO_2e/ha/yr$)**							**Total indirect emissions ($tCO_2e/ha/yr$)**
	Tillage	Sowing	Fertilizer spraying	Pesticide spraying	Combined harvesting	Forage harvesting	Bailing	
Cereals	0.13	0.01	0.24	0.01	0.04	0.00	0.12	0.55
Oilseed rape	0.13	0.01	0.27	0.03	0.04	0.00	0.00	0.48
Root crops	0.13	0.01	0.26	0.02	0.04	0.00	0.00	0.46
Temporary grassland	0.03	0.00	0.33	0.00	0.00	0.00	0.12	0.48
Permanent grassland	0.00	0.00	0.23	0.00	0.00	0.00	0.12	0.35
Rough grazing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	0.10	0.01	0.27	0.01	0.02	0.00	0.00	0.40

(Sources: Lal, 2004)

4.3.5. Estimations of N_2O emissions from different land uses

Data:

N_2O emissions contributed by the use of fertilizers and by the manure of livestock, either spread as slurry or as direct input from the grazing livestock, were considered for this analysis. In order to avoid double counting of emissions from artificial fertilizers and organic fertilizers (manure), the information regarding the N requirements for each land use type and N inputs by both artificial fertilizer and organic manure was used.

The N_2O emissions estimates for fertilizers were calculated by using the N requirement for each land use category, which are; Cereals (187 Kg N/ha/yr); Oilseed rape (210 Kg N/ha/yr); Root crops (200 Kg N/ha/yr); Temporary Grassland (250 KgN/ha/yr); Permanent Grassland (175 KgN/ha/yr); Rough Grazing (0 Kg

N/ha/yr) (Beaton, 2006; Kroeze, 1994). Emissions from each kg of fertilizer (Table 4.5) were taken from Lal (2004).

The estimations for N_2O emissions from farmyard manure included the N requirements and manure excretion for livestock. The manure excretion data was taken from (UKCIP, 2009) and was extended for the livestock numbers and land use distribution for each $2km^2$ across the UK.

Estimations:

The estimates from inorganic fertilizers were calculated by combining the N requirements for each land use category with the emissions from each kg of inorganic fertilizer. The values were converted to carbon equivalents (CO_2e) (Table 4.5).

Table 4.5: N_2O emissions from different land uses according to the Nitrogen requirements from inorganic fertilizers

Farm Activity	**N Requirement (KgN/ha/yr)**	**Emissions (KgN_2O/Kg fertilizer)**	**Conversion Factor (KgN_2O-tCO_2e)**	**Total emissions (tCO_2e/KgN/yr)**
Cereals	187	0.0171	0.296	**0.95**
Oilseed rape	210	0.0171	0.296	**1.06**
Root crops	200	0.0171	0.296	**1.01**
Temporary grassland	250	0.0171	0.296	**1.27**
Permanent grassland	175	0.0171	0.296	**0.89**
Rough grazing (non-peat)	0.00	0.0171	0.296	**0.00**
Rough grazing (peat)	0.00	0.0171	0.296	**0.00**
Other	204	0.0171	0.296	**1.03**

(Sources: Beaton, 2006; Kroeze, 1994; Lal, 2004)

In order to calculate the distribution of N_2O emissions from farmyard manure across the land it was necessary to consider the grazing and housing time periods for livestock. According to Smith *et al.* (2007a) average dairy cattle are housed for 190 days and grazed for 175 days, beef cattle are housed for 151 days and grazed for

214 days, while sheep spend 335 days grazing while they are housed for 30 days only during the year. It was assumed that the emissions are 100% from farmyard manure during housing and 100% from deposition on grasslands during grazing periods. The data used to calculate distribution of manure is presented in Table 4.6.

Table 4.6: N_2O emissions from manure supplied by livestock

Livestock	Excretion (Kg N/head/yr)	Direct application to grasslands		Slurry/Farm applications for other land uses	
		Direct application to grasslands (Kg N/head/yr)	Direct grassland application emissions (tCO_2e/head/yr)	Slurry/Farm applications for other land uses (Kg N/head/yr)	Slurry Application emissions (tCO_2e/head/yr)
Dairy	51.00	24.45	**0.1448**	26.55	**0.0157**
Beef	24.80	14.54	**0.0861**	10.26	**0.0061**
Sheep	10.00	9.18	**0.0543**	0.82	**0.0005**

(Sources: Beaton, 2006; Freibauer, 2003)

4.3.6. Estimations of CH_4 emissions from enteric fermentation

The CH_4 emissions from livestock are mainly from enteric fermentation. These emissions were calculated by using the data from Roulet *et al.* (2007) and are presented in Table 4.7.

Table 4.7: Methane emissions from enteric fermentation

Livestock	Emissions from enteric fermentation (tCH_4/head/yr)	Total emissions (tCO_2e/head/yr)
Dairy	0.1035	0.0023805
Beef	0.048	0.001104
Sheep	0.008	0.000184

4.4. Estimations for GHG flux from agricultural land use change

This section relates to the annual flow of emissions of GHG from land use change. It is comprised of two components: i) Annual SOC fluxes due to land use change. For example, permanent grassland converted from arable farming will be accumulating SOC, while permanent grassland on land that was previously under rough grazing will be losing SOC; and ii) Annual carbon fluxes from changes in vegetative biomass associated with land use changes.

For the Baseline year (2004) annual flows of SOC were only estimated for organic (peat) soils as there is insufficient data on land use change prior to the baseline to accurately model changes in SOC in non-organic soils. In the analysis of the subsequent years, SOC flows from both organic and nonorganic soils due to land use change were included. Annual SOC fluxes were based on the assumption that organic soils sequester carbon under rough grazing. Estimates for SOC sequestration rates in organic soils vary from 0.18tC/ha/yr (Turunen *et al.*, 2002) to 0.36-0.73tC/ha/yr (Worrall *et al.*, 2009). For this analysis an average of six estimates found in the literature was taken as 0.3tC/ha/yr, and was assumed as the SOC accumulated in peat under rough grazing. Under arable/horticultural land uses it was assumed that 1.22tC/ha/yr of SOC would be released from peat soils, and 0.61tC/ha/yr would be released from peat soils under improved grassland (Foley *et al.*, 2005). For nonorganic soils it was assumed that mean equilibrium SOC levels would change from those associated with the previous land uses to the SOC levels associated with the new land uses (see Table 4.1). SOC storage and SOC emissions were assumed to occur evenly over a 100 year and 50 year period respectively (Thomson *et al.*, 2007). For example, a hectare of nonorganic soil in England converted from cereals to permanent grassland was assumed to accumulate 22 tonnes of SOC before it reached a new equilibrium.

Emissions and accumulations of carbon in terrestrial vegetative biomass were based on the change in vegetative biomass in the move from one land use to another. The change in equilibrium vegetative carbon stock estimates for each 2 km^2 grid (see

Table 4.2) was divided by the time period over which the change occurred to provide an estimate of the annual vegetative GHG fluxes from EFH. Where the modelled annual accumulation of carbon in terrestrial vegetative biomass was lower than the baseline year, then a net emission of GHG was considered. It was assumed that the accumulation and emissions of GHGs associated with unchanged land uses were zero, with annual emissions balancing annual sequestration. Total GHG fluxes from agriculture are simply the sum of SOC fluxes, vegetative biomass carbon fluxes and fluxes from agricultural activities within each 2 km^2 grid.

4.5. Results and discussions

The results are illustrated by mapping the baseline year (2004) against scenarios for high and low emissions for the years 2020, 2040, and 2060. The analysis of the changes in annual greenhouse gas emissions from changes in land use management is also presented and illustrated by mapping the Business as Usual scenario (BAU) against the outputs from the scenario analysis.

4.5.1. Evaluation of the changes in carbon storage capacity

a. Carbon stocks for baseline year

This analysis provides a total UK estimate of vegetative carbon stocks for the baseline year (2004) of 134MtC, of which 77% is stored in woodlands. This compares with Milne and Brown’s (1997) estimate of 113.8±25 MtC for GB with 80% stored in the woodland (Dale, 1997). Figure 4.2 shows the potential equilibrium vegetative carbon stock (a), SOC stock (b), and combined vegetative and SOC stocks (c), for the baseline year 2004. From Figure 4.2 it is clear that the vegetative stocks are quite evenly spread across the UK, with the highest stocks in the forested areas, while SOC is highest in the upland peat. 50% of the carbon stocks are found in Scotland (2365 MtC), with a further 37% (1755 MtC) in England, 7% (338 MtC) in Wales, and 6% (292 MtC) in Northern Ireland.

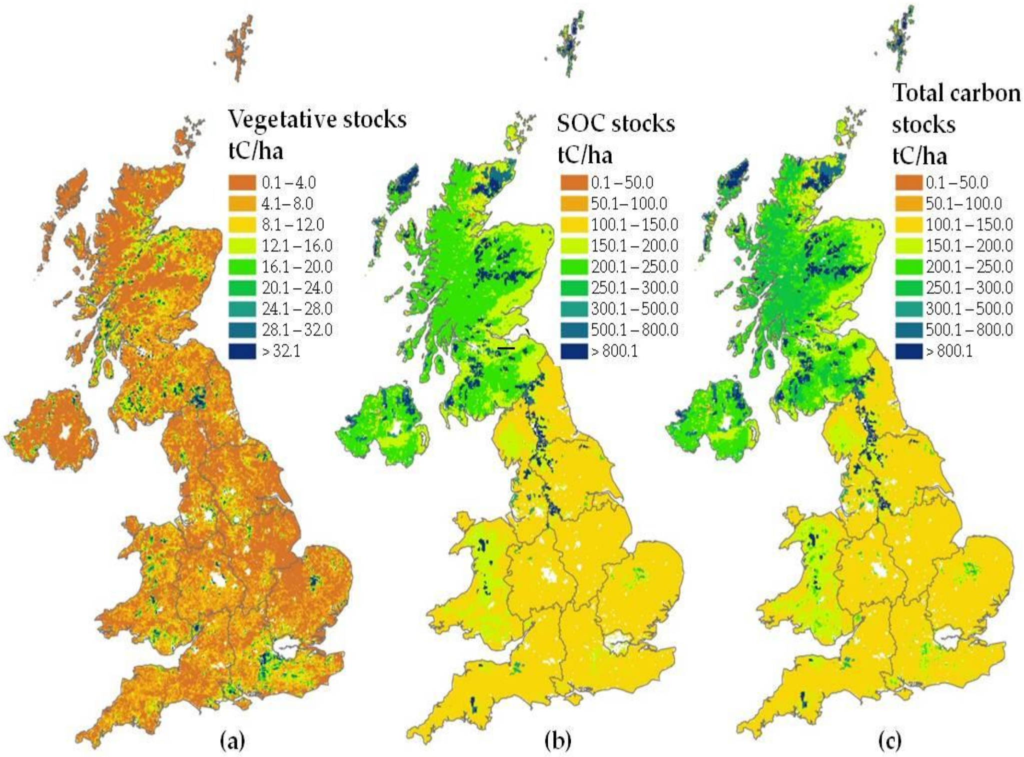

Figure 4.2 Baseline potential equilibrium carbon stocks for the UK

b. Changes in carbon stocks under UKCIP scenarios

With the exception of projected moderate increases in carbon stocks in 2040 for Northern Ireland (due to increased rough grazing), only some parts of east England and parts of the north east Scottish Highlands show a consistent increase in carbon stocks, again due to a reversion of land use from arable farming to rough grazing/semi natural grasslands. The largest reductions in carbon stocks occur in peat land and uplands in the UK. There is a significant reduction in potential equilibrium carbon stocks in the lowland agricultural regions of southern England, in both low and high emissions scenarios, but the losses are more prominent in the high emissions scenario for the year 2060.

Figures 4.3 and 4.4 show the regional changes in carbon stocks for two climate scenarios. The patterns are quite similar across both, although changes in the southern regions increase more rapidly in the high emissions scenario. The total reduction in potential UK equilibrium carbon storage from the baseline year to 2060 is 1,381 MtC for the low emissions scenario and 1,560 MtC for the high emissions scenario, this would equate to total CO_2 emissions of approximately 5,064 MtCO_2e and 5,719 MtCO_2e respectively. The total UK emissions of GHGs in 2008 have been estimated as 6,285 MtCO_2e (Yearley, 2009).

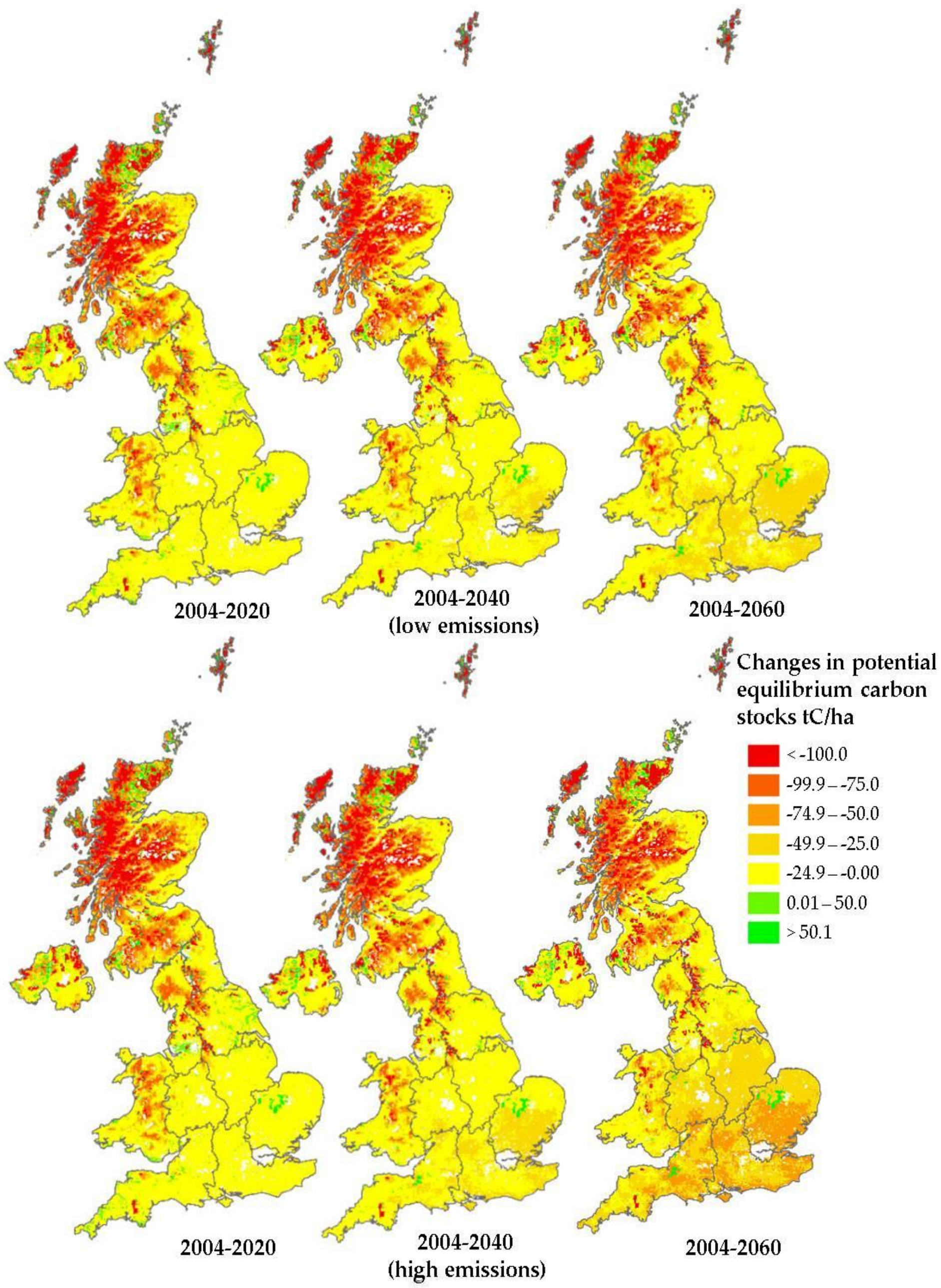

Figure 4.3: Changes in potential equilibrium carbon stocks for the UK due to land use changes under two UKCIP emissions scenarios

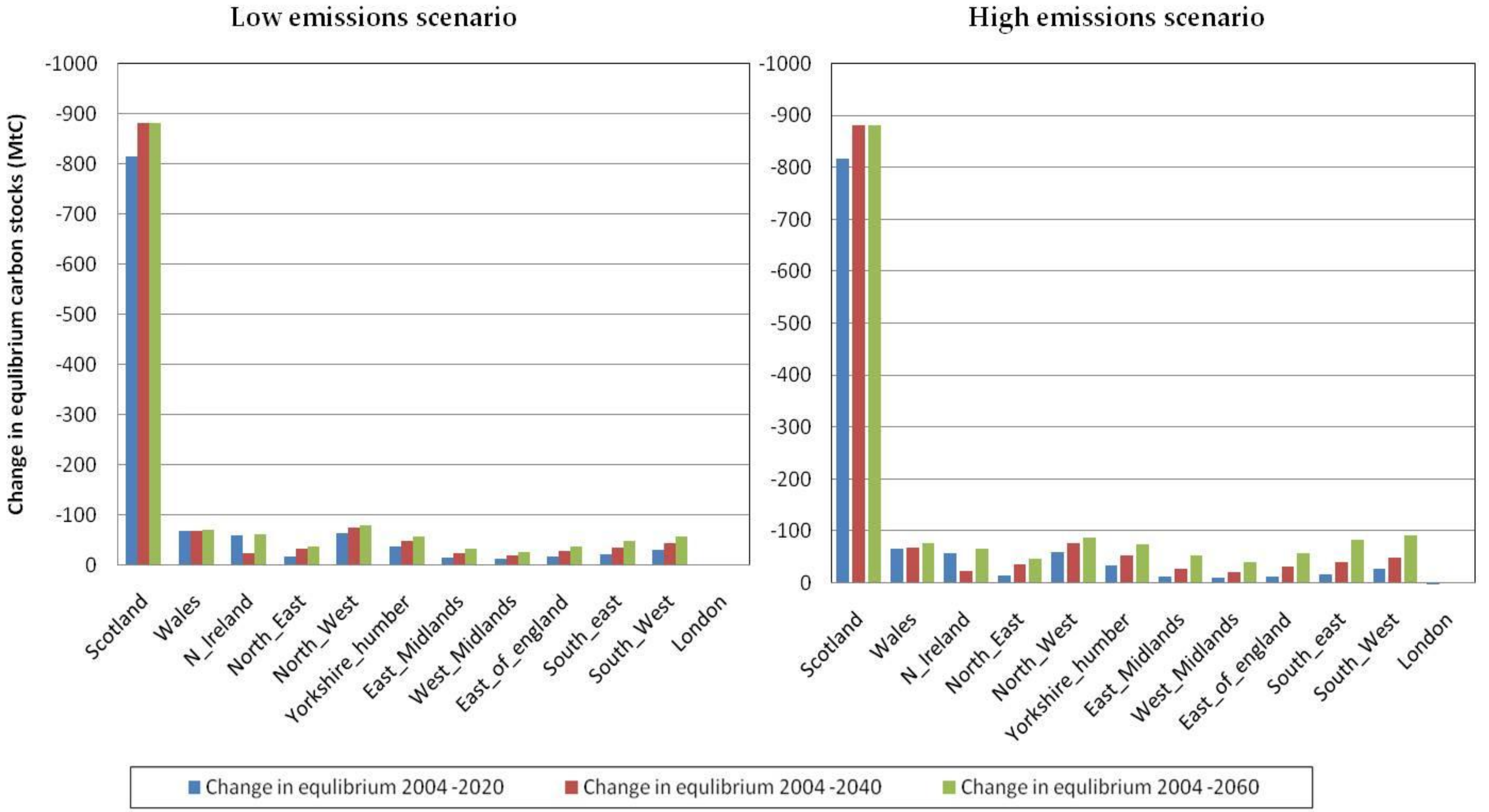

Figure 4.4 Regional changes in potential UK equilibrium carbon stocks due to land use change under two climate changes scenario

4.5.2. Evaluation of the changes in GHG flux

The GHG flux in UK enclosed farmlands are due to the indirect emissions from farming activities (including emissions due to manufacture and application of external inputs, direct emissions from both artificial fertilizers and farmyard manure from livestock, and direct emissions from enteric fermentation in livestock (dairy, beef and sheep) (Figure 4.5).

The annual GHG fluxes for baseline years are estimated to be 35 MtCO_2e. Official estimates for the GHG emissions from agriculture for 2004 range from 44.53MtCO_2e (Thomson *et al.*, 2007) to 51.7 MtCO_2e (Yearley, 2009). It was expected that the analysis presented here would have estimates below the official figures because the emissions for pig and poultry farming, or carbon emissions from soils (due to lack of spatially explicit data on land use change prior to 2004), are not included. In 2004 emissions from enteric fermentation and direct release of N_2O from the application of both artificial fertilizers and farmyard manure represent the highest source of GHG emissions. Emissions were highest in the south of England, and lowest in the extensively farmed upland areas in the UK.

The changes in annual GHG fluxes from agricultural activities and agricultural land use change under the two UKCIP climate changes scenarios are illustrated in Figure 4.6. The negative values represent net reductions in annual emissions, while positive values represent net increase in GHG emissions from agriculture. Both scenarios show considerable changes in annual emissions, with lowland areas of England showing a decrease in emissions, and the largest reductions in the South West of England. Wales, Northern Ireland, Scotland and northern upland areas of England are all predicted to show an aggregate increase in carbon emissions due to increased livestock numbers and a greater presence of arable and horticultural production, leading to increased emissions of N_2O and methane. The conversion of peat land from rough grazing/semi-natural grassland to improved grassland is also a potentially large source of increased GHG emissions. While the emissions per hectare are more pronounced in the high emissions climate scenario, the overall predicted emissions from agriculture are similar for both scenarios, with UK GHG emissions for EFH estimated as moving from 1.54 tCO_2e/ha/yr to 1.69 tCO_2e/ha/yr in 2060 (low emissions scenario), and 1.65 tCO_2e/ha/yr in 2060 (high emissions scenario). This equates to an aggregate increase in UK GHG emission for agriculture of approximately 11% between 2004 and 2020, under both emissions scenarios. Table 4.8 provides a detailed analysis of the percentage of change in the UK annual GHG emissions from enclosed farmlands.

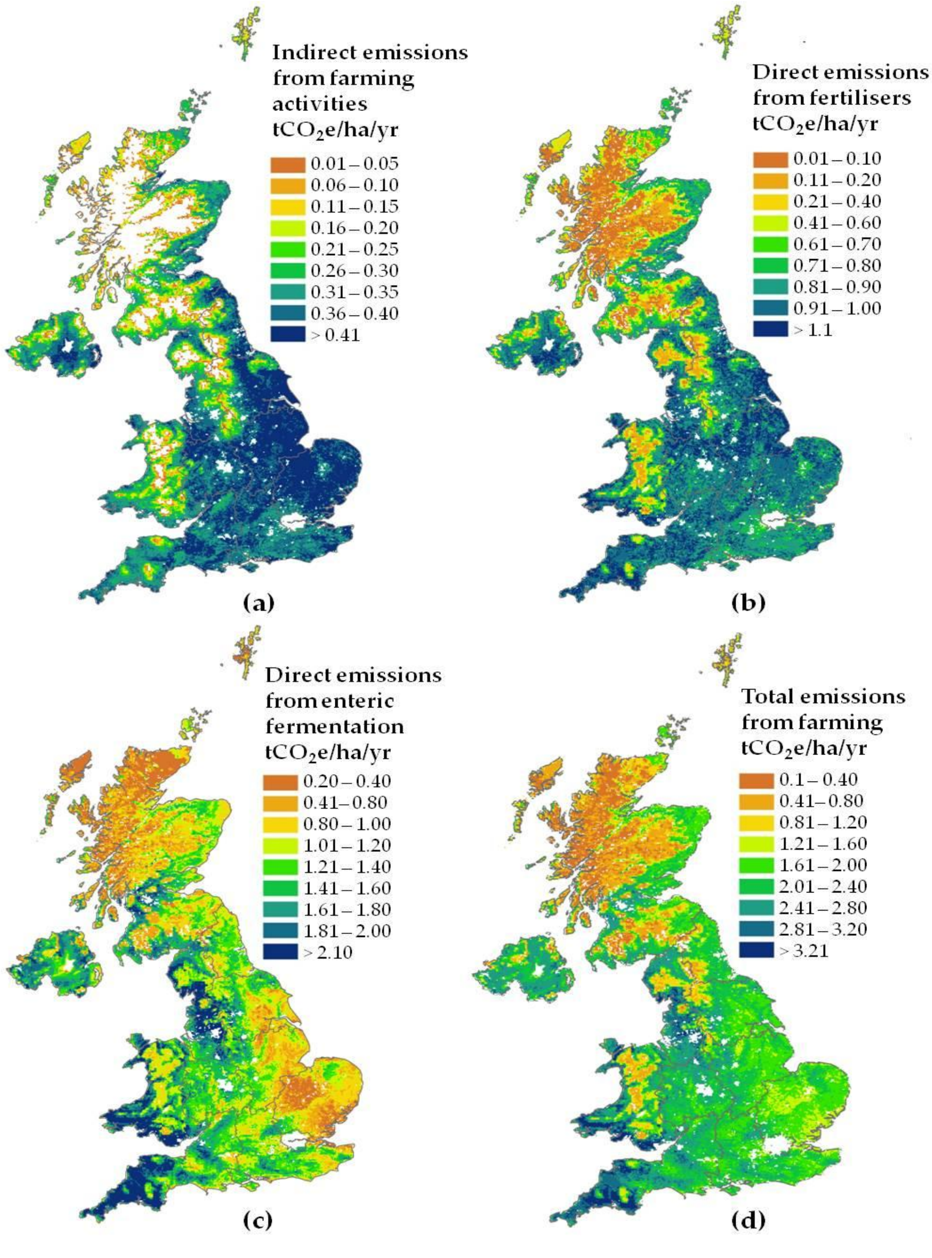

Figure 4.5: Estimated CO_2 flux from the UK farmlands for the year 2004

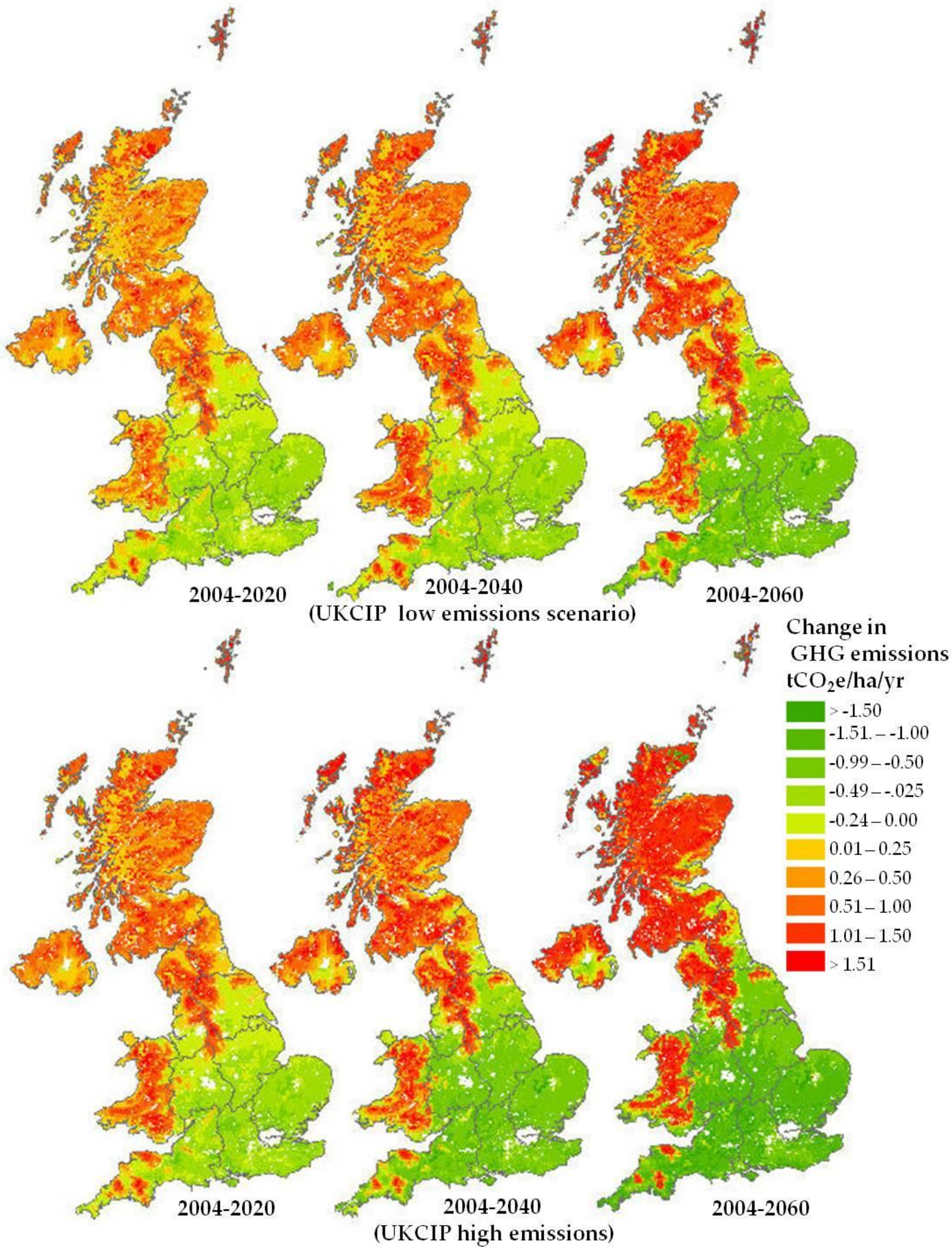

Figure 4.6: Estimated Changes in GHG emissions from enclosed farmlands

Table 4.8: Changes in regional carbon fluxes from the baseline year from enclosed farmlands

Regions	UKCIP low emissions Scenario			UKCIP high emissions scenario		
	Change in carbon fluxes 2004 - 2020	Change in carbon fluxes 2004 - 2040	Change in carbon fluxes 2004 - 2060	Change in carbon fluxes 2004 - 2020	Change in carbon fluxes 2004 - 2040	Change in carbon fluxes 2004 - 2060
Scotland	42.4%	56.9%	66.1%	39.8%	60.4%	82.1%
Wales	19.9%	23.0%	22.2%	19.1%	23.4%	18.3%
Northern Ireland	18.7%	21.6%	22.2%	17.8%	23.0%	22.1%
North East	18.7%	20.2%	19.1%	18.0%	21.0%	15.8%
North West	18.1%	21.2%	21.3%	17.3%	21.9%	20.3%
Yorkshire Humber	8.2%	6.0%	2.2%	8.4%	4.8%	-3.8%
East Midlands	-5.2%	-12.8%	-20.3%	-3.6%	-15.7%	-30.1%
West Midlands	-3.6%	-11.7%	-20.4%	-2.3%	-14.6%	-32.4%
East of England	-14.1%	-21.0%	-27.6%	-11.3%	-23.4%	-37.1%
South East	-14.3%	-23.8%	-33.0%	-10.4%	-27.6%	-45.4%
South West	-1.8%	-8.0%	-16.6%	-0.3%	-11.3%	-30.7%
London	-17.4%	-26.7%	-35.5%	-13.2%	-29.6%	-46.4%
UK average	**11.5%**	**11.8%**	**9.7%**	**11.7%**	**11.3%**	**6.7%**

The regional analysis of changes in annual carbon emissions from agriculture (Figure 4.8) shows an overall increase in emissions, most of which comes from Scotland, the North of England, Wales and Northern Ireland. Scotland is predicted to move from being the lowest emitter of agriculture related GHGs to one of the highest, while Northern Ireland GHG emissions from agriculture are predicted to exceed 3tCO_2e/ha/yr under both emissions scenarios by 2020. These estimates do not include annual fluxes of SOC in peat soils as they are included in the stock analysis. In the baseline year net carbon emissions from UK peat soils is estimated at 3.76MtCO_2e/yr increasing to 7.67 MtCO_2e/yr by 2060 (high emissions scenario), with Scotland accounting for almost half of these emissions (1.56 and 4.19MtCO_2e/yr in 2004 and 2060 respectively). These emissions are due to land use change, mainly from rough grazing to more intensive agricultural land uses such as permanent grasslands.

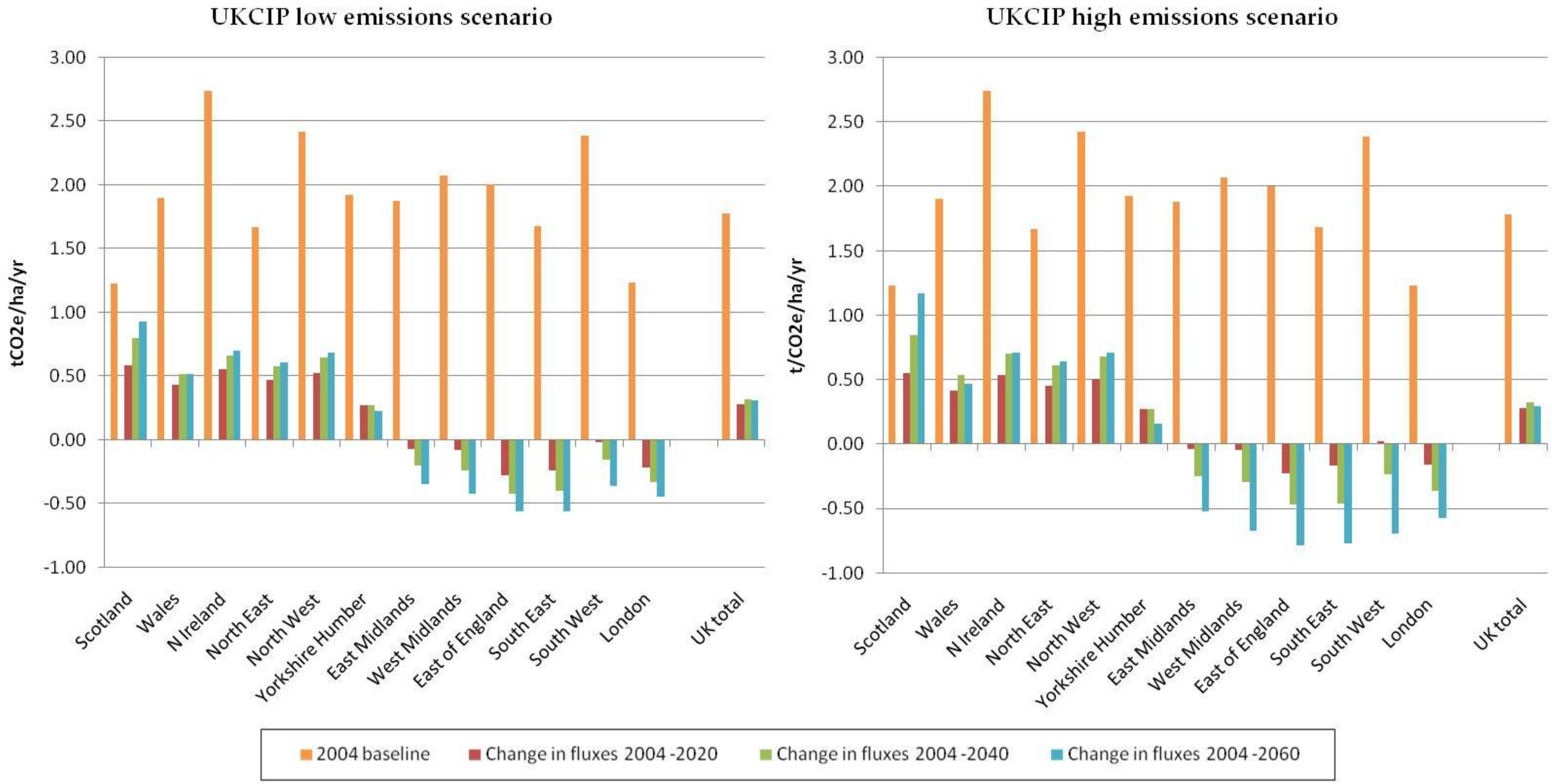

Figure 4.7: Estimated changes in GHG emissions from UK agriculture from 2004-2060 under two climate scenarios

4.5. Conclusion

This chapter investigates the changes in regulatory service provided by UK farmlands. It employs outputs from a structural land use model to assess the changes in the regulating service over time (2004-2060), based on UKCIP scenarios. The study shows that climate change has a major impact on UK agriculture. The analysis presented in this chapter shows that there are large variations within the enclosed farmland habitats across the UK with respect to the climate change scenarios. The estimations suggest that agricultural responses to climate change over the next 50 years may lead to significant changes in UK land use and a regional disparity in resultant changes to GHG emissions.

The spatial analysis indicates that northern parts of the UK are expected to see a decrease in potential carbon stocks and rising GHG emissions due to increased agricultural intensification as the climate warms. On the other hand, the southern parts of the UK are predicted to see small increases in carbon stocks and associated falls in annual agricultural emissions because of a shift from cereal cropping towards grasslands due to a projected drier hotter climate in the future. Overall, these changes may have significant impacts on UK attempts to decrease GHG emissions, as agricultural emissions are estimated to increase by around 11% over the next two decades considering the climate induced agricultural land use change.

The study reveals that adjustments in land use induced by climate change will help to mitigate agricultural GHG emissions in some regions, while in others it will have the opposite effect. The cost of provision of carbon from the providers (farmers) perspective can prove to be more useful for directing future policies. Such a carbon cost analysis both from the literature and from real data, collected from farmers for this thesis, will be attempted in Chapter 7.

The study concludes that climate change is likely to cause changes, directly and indirectly, in carbon stocks through land use change. The heterogeneity in land use and changes in emissions in response to climate change lead to the need for designing policies for land managers to adopt changes in land use management. Effective policy instruments may have to combine incentives, restrictive regulations and interventions to encourage the land use managers to adopt land use changes to contribute towards reducing (enhancing) emissions (carbon sequestration) on their farms. An assessment of potential designs for such policies is presented in Chapters 5 and 6, for the major farm types (arable and livestock) in the UK.

The estimates calculated for this study were very much in accordance with the most comprehensive UK SOC estimations provided by Bradley *et al.*, 2005 (with only a 1.3% discrepancy). Significant regional changes were predicted, revealing an increase in GHG emissions in the north and western parts of the UK and a decrease in the lowland south and east of the country. This is attributed to the changes in land use management partly induced by climate change. This provides the basis for addressing the mitigation of climate change, through changes in agricultural activities. Combining the estimations from this study with carbon values can help to identify the potential cost of potential GHG mitigation in this sector. Furthermore, identifying potential cost effective policy schemes for enhancing the regulatory service can also provide a step forward for UK farmlands to contribute towards the national GHG mitigation targets. This will be attempted in the following three chapters of this thesis.

Chapter 5 Investigating farmers preferences for payment schemes to promote climate change mitigation

Abstract

This chapter reports the results of a CE study to determine the willingness to participate in a policy scheme designed to mitigate greenhouse gas (GHG) emissions from livestock farms. As described in the survey design (see Appendix A), the CE questionnaire was administered to 380 farmers. The respondents were presented with two potential payment schemes, one for mitigation of GHGs from livestock farms and the other for carbon sequestration in arable farmlands. The respondents opted to participate in the payment schemes according to their farm types, therefore, some of the farmers with mixed-farms, responded to both (mitigation and sequestration) payment scheme questionnaires. This resulted in 329 responses for the mitigation payment scheme while 115 responses were obtained for the sequestration payment scheme. The responses were analysed using three discrete choice models and the results for the mitigation payment scheme are reported in this chapter (for the sequestration payment scheme, refer to Chapter 6). Random parameter Logit and Latent Class models were used to analyse the farmers' responses to investigate their preferences, heterogeneity in their preferences and the willingness to accept values estimates. It was found, in general, that farmers show strong aversion to drastic changes in land use management; however, flexibility in certain scheme attributes can help to attract farmers. Socioeconomic characteristics like livestock units, farm income, age, and farm size proved to have significant effect on the behaviour of the farmers. These results can aid in designing policy schemes for climate regulation in the UK, with possible implications for the delivery of other ecosystem services from farmland.

5.1. Introduction

Agro-ecosystems are widely recognised to provide many services that contribute to the well-being and economic prosperity of human kind, from provisioning services, regulatory services to recreational opportunities. This type of ecosystem is the one that is most directly managed by humans and occupies approximately 40-50% of the earth's surface (Smith *et al.*, 2007b; Swinton *et al.*, 2007). Agricultural lands have always been given importance for their provisioning services (food, fuel, fibre, etc). Along with this they also have the capacity to provide regulatory services like regulating levels of water supply, carbon storage, and greenhouse gas emissions. However, agricultural land also accounts for 10-14% of global (Smith *et al.*, 2007c) and 7% for the UK's greenhouse gas emissions (NFU, 2005) and under the Climate Change Act, 2008, the UK government is committed to reduce national emissions by 80% of 1990 levels by 2050 (Moran *et al.*, 2010).

The valuation of environmental goods and services provided by agroecosystems can be helpful to address the degradation being caused to these ecosystems and their services. For agri-environmental policy assessments, monetary estimates are the basis for economic evaluations (Huber *et al.*, 2011). PES schemes are an important policy instrument for improvement in ecosystem services. These schemes can help to establish both improvements in the environment and in welfare gains of ecosystem managers by linking the beneficiaries of the services to those who deliver them (Defra, 2010). Various payment schemes have been used in agricultural ecosystems for the provision of different ecosystem services (such as biodiversity conservation, watershed protection, carbon sequestration, and landscape improvements). Instruments such as agri-environment schemes are being used to enhance the efficiency of supply of the ecosystem services associated with agriculture (Sauer and Wossink, 2010) and are an important component of the EU agricultural policies in the UK. These agreements have attracted increasing global attention as they have changed ecosystem services into financial incentives for local land managers (Engel *et al.*, 2008) by compensating them for any income loss or increase in costs incurred by the part they play in providing the environmental goods.

The voluntary nature of PES schemes means that the farmers' decision to participate is of utmost importance to achieve the policy objectives of the schemes (Wilson, 1996). According to Wilson and Hart (2000) it is important to understand the motivations of farmers to participate in payment schemes, as participation is an 'indicator' of scheme effectiveness. There has been considerable research interest in the design and scope of PES schemes. It is imperative that PES schemes must be properly designed and implemented to achieve the aim of the scheme effectively (Layton and Siikamäki, 2009). Several studies have assessed the potential participation of land owners' in PES schemes by determining the factors affecting their behaviour (Paulrud and Laitila, 2010; Thacher *et al.*, 1997; Vanslembrouck *et al.*, 2002; Vignola *et al.*, 2010). Others have addressed improvements in PES scheme designs by concentrating on farmers preferences for different scheme attributes (Broch and Vedel, 2012; Espinosa-Goded *et al.*, 2010; Ruto and Garrod, 2009; Tesfaye and Brouwer, 2012) utilising CE techniques because of the non-availability of real data. A few of these have focused on European case studies (Beharry-Borg *et al.*, 2012; Broch and Vedel, 2012; Espinosa-Goded *et al.*, 2009; Ruto and Garrod, 2009).

It is important to account for any heterogeneity in land managers' behaviour in order to make a better-informed case for improving climate regulation policies for agricultural sector. This chapter and the one following (Chapter 6), present a study in the UK to assess the design of two potential payment schemes specifically addressing climate regulation by looking into the participation behaviour of the UK farm owners. Various studies (such as IGER, 2001; Moran *et al.*, 2008; Smith *et al.*, 2008) have identified feasible and cost-effective measures to enhance mitigation of emissions and carbon sequestration. These two chapters explore whether payment schemes would generate reductions (increases) in emissions (carbon sequestration) and if they would be adopted by the farming community in the UK. This is carried out by investigating the participation (non-participation) of farmers in potential PES schemes, by considering the role of scheme design and farmers (farm) socio-economic characteristics. The potential use of payments provided to farmers as incentives to adjust their agricultural land management practices to contribute towards this ecosystem service is examined. The study focuses on two potential payment schemes simultaneously for both arable and livestock farmers and reports on farmers' preferences for key attributes of the payment schemes.

This chapter will present a description and design of the mitigation payment policy scheme and the model estimations for this policy only. The sequestration policy scheme is discussed in detail in Chapter 6. The chapter begins (Section 5.1) by introducing farmers preference heterogeneity and the importance of investigating this heterogeneity for UK farmlands in the climate change context and in view of the specific research question addressed. Section 5.2 provides a review of the related literature explaining the development of the mitigation policy scheme and the study framework adopted for this analysis. This is followed by an account of the attributes and levels defining the mitigation policy scheme in Section 5.3. Section 5.4 presents a short description of the experimental design. Section 5.5 provides the descriptive statistics of the survey and the parameter estimations of the discrete choice models, which include the conditional logit model (CLM), random parameter logit model (RPL) and Latent Class model (LCM). The latter two models are used to investigate the presence of taste heterogeneity of the respondents' preferences. The parameter estimates from the model specifications are then used to calculate the WTA estimates (Section 5.6) and also the results of individual-specific WTA values are calculated and presented using kernel density graphs for each attribute. A discussion of the estimation results is presented in Section 5.7. Finally the chapter ends with the conclusions of the study (section 5.8).

5.2. Theory and Methods

5.2.1. Related literature

Understanding the participation in payment programmes is of vital importance and can inform policy makers for future policy decisions related to the development of payment schemes. Farmers' participation in payment schemes and the factors affecting their participation decisions have been under discussion for quite some time. Brotherton (1989) suggested that both farmers' attitudes and scheme attributes affect the participation decision. Wilson (1997) also studied the factors influencing participation of farmers in the Environmentally Sensitive Area (ESA) scheme, using Brotherton's classification. Later Falconer (2000) carried out a similar investigation into farmers' behaviour towards Agri-environmental Measures (AEMs) for eleven regions across Europe. From a further review of studies (for example, see Brotherton, 1991; Potter and Gasson, 1988; Thacher *et al.*, 1997; Wilson and Hart, 2000; Wilson and Hart, 2001) it was possible to categorise the factors as: i) socio-demographic elements; ii) household characteristics; iii) farm business characteristics; and iv) farm characteristics.

More recently, studies have investigated the preferences of farmers for different scheme attributes. Identifying the factors affecting the farmers' participation decision can help to both improve existing payment scheme designs or to develop new schemes overcoming barriers for farmer participation (e.g. Broch and Vedel, 2012; Espinosa-Goded *et al.*, 2010; Ruto and Garrod, 2009; Wilson, 1997). Several studies have addressed the heterogeneity in farmers participation behaviour (see Hudson and Lusk, 2004; Ruto and Garrod, 2009; Vanslembrouck *et al.*, 2002; Wilson and Hart, 2000). This heterogeneity has also been linked to variables including farm/farmer characteristics such as household income, land use opportunity cost (Wunder *et al.*, 2008); farm size (Ayuk, 1997; Caveness and Kurtz, 1993; Thacher *et al.*, 1996); farm production capacity, farmers age (Potter and Lobley, 1992; Wynn *et al.*, 2001), and farm income (Nowak, 1997). Maynard and Paquin (2004) have suggested that participation is dependent upon the payment scheme developers' ability to include strategies to gain the confidence of the farmers to take up the schemes. According to Dupraz *et al.* (2003), a better understanding of the utility of the measure can make a participation decision more likely. Hudson and Lusk (2004) investigated six attributes of possible importance and found a preference for increasing income, minimising risk, keeping autonomy and shorter contracts. Horne (2006) explored forest owners' acceptance of incentive based policy instruments for biodiversity conservation. She finds that forest owners preferred restrictions on small areas, short contracts and to be able to cancel the contract. Beharry-Borg *et al.* (2012) studied the potential drivers of participation in a payment programme for water quality protection. The study revealed that considerable heterogeneity of preferences appeared to exist between farms/farmers: a small proportion of farmers appeared very reluctant to commit to change their management practices while a considerable number of farmers were willing to modify their land management practices if high enough compensation was available.

Findings of several studies also suggest that farmers can be extremely resistant to participation (Espinosa-Goded *et al.*, 2010; Ruto and Garrod, 2009), however, farmers do appear to trade-off compensation payments with flexibility in land use management restrictions, length of agreement and amount of paperwork involved (Christensen *et al.*, 2011; Ruto and Garrod, 2009).

However, none of the recently published studies have specifically addressed farmers' WTA requirements for climate change mitigation in the agri-environment sector. This study specifically looks at the potential of developing anaerobic digestion (AD) for reducing methane emissions from UK farmlands (especially livestock and mixed farms). Therefore, this study involves ex-ante evaluation of farmer uptake of attributes of a mitigation payment scheme, to analyse the impact of different attributes and attribute levels on their participation behaviour.

For this thesis, the SP method was considered appropriate because this study is based on hypothetical payment schemes and no revealed data are available (see detail of the methodology in Chapter 3). This approach also made it possible to combine both qualitative (technical assistance, plant ownership) and quantitative (compensation levels, length of agreements, generator capacity and distance) attributes in one design.

The aim of this chapter is to investigate landowners' payment scheme preferences for mitigating GHG emissions from UK farmlands and to suggest scheme design for developing effective policies for attracting farmers to contribute towards the UK's emission reduction targets. To achieve this aim, the following objectives were identified:

- Estimating farmers WTA requirements for adoption of GHG mitigation policy for potential reduction in GHG emissions from livestock farms.
- Exploring the extent of heterogeneity for a potential mitigation policy and investigating whether this heterogeneity is associated with particular farm or farmer characteristics.

5.2.2. GHG mitigation through Livestock farms

The potential mitigation payment scheme was described for GHG mitigation specifically from livestock. The major GHG emissions from livestock farms are methane and nitrous oxide. Methane is produced by enteric fermentation from ruminant animals and from slurry storage. Nitrous oxide emissions are mainly from the manure produced by livestock due to excretion of nitrogen. The selected mitigation policy scheme involved setting up Anaerobic Digestion (AD) plants on the farms for the capture of CH_4 (with a global warming potential[1] of 21 times higher than CO_2). It is also considered to be a cost-effective method of reducing emissions (methane) from manure (Bywater, 2011), to some extent from fossil fuels (carbon dioxide) due to bio-fuel production and from the use of artificial fertilizers as the digestate from the plant is a used as organic fertilizer and reduces the requirements for artificial fertilizers. The biogas produced after the anaerobic digestion in the

[1] Global warming potential (GWP) is a measure of the total energy that a gas absorbs over a particular period of years compared to CO_2. CO_2 has a GWP of 1 which serves as a baseline for other GWP values.

plants consists mainly of methane (55-75%) and carbon dioxide, with small volumes of nitrogen, hydrogen, hydrogen sulphide and oxygen (Bywater, 2011).

AD plants potentially have the ability of improved slurry handling (proper storage, handling and spreading), and to meet a farm's energy and fertiliser requirements; which makes them a very useful tool. After the treatment process the digestate from the AD plant has no strong odour, is easily spreadable, and improves nutrient recycling and uptake (Tranter *et al.*, 2011). The underlying idea for AD plants is that the slurry is scraped daily to capture the GHG emissions (especially CH_4) and the plants then generate renewable energy by using the biogas directly in a boiler for heating purposes and renewable electricity which can be fed into the national grid. This provides an opportunity for the farmers to not only reduce their energy bills and farm GHG emissions but can also provide economic benefits by selling the surplus energy and digestate (Defra, 2009). Biogas production from AD plants can prove to be advantageous for both livestock and arable farmers. It provides an opportunity for the livestock farmers to generate income from the manure of the livestock and improve the quality of fertilisers and at the same time it can provide a profitable alternative of a 'break crop'[2] to the arable farmers.

AD plants can be either on-farm AD (OFAD) units for a single farm or larger centralised AD (CAD) units to deal with waste products from a number of farms. AD plants are quite popular in mainland Europe and are mostly found in Germany, Denmark, Austria and Sweden. Around 4000 OFAD units are in operation in Germany while larger CAD units have been set up mostly in Denmark and are integrated into the renewal energy production system (Wilkinson, 2011). The main success of these plants can be attributed to the design simplicity of the plants along with conducive governmental regulations and policies which makes it feasible for farmers to set up these plants (Lusk, 1998).

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[2] A break crop is any crop sown as a crop rotation to provide diversity to help reduce disease, weed and pest levels Kirkegaard, J., O. Christen, J. Krupinsky & D. Layzell. 2008. Break crop benefits in temperate wheat production. *Field Crops Research,* **107** (3), pp.185-195..

There is a significant potential for AD plants to contribute to UK climate change objectives, as about 100 million tonnes of slurry are produced on UK farms (Defra, 2010). This causes GHG emissions, odour and potential run-off to water resources causing pollution and eutrophication. The uptake of AD plants in the UK has been very small; still according to DEFRA (2012) 78 AD plants are currently under operation in the UK of which 48 plants treat waste feedstock while only 29 treat farm feedstock with one CAD in Devon (Bywater, 2011). The failure of UK farmers adopting AD plant technology has been associated with a lack of economic returns, insufficient financial incentives through agri-environmental schemes or payment schemes, lack of recognisable level of additional income for the farmers, non-availability of soft loans, absence of technical assistance, and lack of operational knowledge (Mistry and Misselbrook, 2005).

The UK government has also recognised AD plants potential towards mitigating climate change and other environmental problems and is focusing on encouraging farmers and farming organisations towards the development and use of this technology. The need for developing a more effective system and drivers to attract the farmers in UK towards adoption of AD plants has been identified by Bywater (2011). Defra established an action group which has devised an action plan in order to address the challenges the AD sector faces in the UK. According to Defra (2009) National Farmer Union (NFU) expects 1000 OFADs on UK farms by 2020. Incentives provided by the government which are developed for renewable energy technologies and are also applied to AD plants, include Renewable Obligation Certificates (ROCs), renewable energy Feed-In Tariffs (FITs) and Renewable Heat Incentives (RHI). Financing has always been a major barrier to the development of the development of small scale OFADs. However, the UK government and other organisations are taking positive steps to overcome this. In 2011, the government announced that it will promote community-scale renewable energy projects through a Rural Community Renewable Energy Fund (DEFRA, 2012). Similarly, both retail and corporate banks are also coming forward to fund AD projects. It has been suggested that the retail sector could provide funds as loans as part of environmental and corporate social responsibility obligations (*ibid*). Nevertheless, banks seem to be reluctant and still not ready to lend money to implement an unfamiliar technology (Bywater, 2011).From the literature available the costs associated with establishment of AD plants vary from £150,000 to £1 million, depending on the size and generating capacity of the plants (Farming Furtures., 2013). On the other hand it is also worth mentioning that most of the existing case studies have shown that revenue generation is quite high in terms of energy savings, profits from export of energy, and gate fees[3] especially for centralised units etc. The projected pay-back time for most of the UK case studies (Bywater, 2011; Farming Furtures., 2013) is considered to be between 5 and10 years.

A review of the case studies suggests that most of the farmers who have set up OFAD plants have been satisfied with the revenue returns from their respective plants. Although Feed-in tariffs have proved to be helpful, it is still not enough to encourage more farmers to invest in ADs.

Therefore, the aim in this chapter is to explore whether payment schemes could be designed to attract the UK farming community to adopt AD plant options to contribute towards reduction in UK GHG emissions. The attempt of this study to investigate participation behaviour can help to inform future policy design by incorporating the identified preferences of farmers.

5.2.3. Study framework

This chapter utilises a CE approach to evaluate a PES scheme design for farmers' willingness to contribute to GHG mitigation (from livestock manure) as an environmental service specifically in UK livestock farms. The first step towards conducting a CE study is to define the policy scheme by suitable attributes and attribute levels appropriate for potential scheme design (for details please refer to a detailed CE design included as Appendix A).

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[3] Gate fee, is the fee charged by an AD plant owner, for disposal of organic waste by various companies into the AD plant.

The CE survey was designed to cover main farm types and to have a sample representative covering the national extent of the UK. To achieve this, various farmers markets, livestock auction markets, annual farming expos and annual dairy and livestock events were selected to conduct the survey. In total, 329 face-to-face questionnaires were conducted.

The choice data and the socio-economic data collected from the surveys was then used to evaluate farmer up-take of potential payment scheme design features to analyse the impact of different attributes and attribute levels. Simple logit models along with the RPL and LCM were utilised simultaneously. First CLM was employed to account for different socio-demographic characteristics of the farmers. Then, RPL was used to identify the existence of preference heterogeneity followed by LCM estimates with finite classes for individual segment-specific utility parameters. This helps to provide a better understanding of the underlying preferences (Ruto and Garrod, 2009) and heterogeneity in farmers' behaviour. The willingness to accept requirements were then calculated and the effects of farm/ farmer characteristics on these requirements were also analysed. This was done by using individual segment specific WTA estimations.

5.3. Attributes for mitigation policy scheme

The first step for CE design is to define the policy scheme in terms of its attributes and potential levels. Identification and correct specification of relevant attributes and levels describing the hypothetical scenario is important so that they can be relevant for both land managers and policy makers. Significant attributes were identified and their levels were chosen to be realistic and represent possible future values if policy measures were to be implemented (Bennett and Blamey, 2001). The range of levels was selected to represent each attribute according to the size and scale of the improvement the farmers are willing to carry out. The choice and selection of the attributes and levels was based on a combination of evidence from the findings in the existing literature of agri-environment schemes across Europe and information from the pilot study of this research.

The mitigation policy scheme, as already described in section 5.2.2., was developed predominantly for livestock farms and required the farmers to provide all the manure produced from the housed livestock to an anaerobic digestion plant and in return generate energy which can be used not only for farm energy requirements but the surplus can also be exported to the national grid providing farmers with additional monetary benefits. This policy required the farmers to set up AD plants for heat and electricity generation according to the size of their farms and the number of livestock units they managed. Issues and problems faced by the existing plants were also considered and were addressed in the design of the policy. The potential payment scheme was described in terms of 6 attributes, four of which were described in quantitative terms while the other two were qualitative. The respondents were informed that if they are provided with an opportunity to setup an anaerobic digestion plant would they prefer to participate in a payment scheme which would help to mitigate the manure emissions from the livestock on their farm. For this purpose the respondents were briefed about the funding opportunities available for setting up such plants (such as government funding or non-governmental or private grants) and the revenue they might be able to generate from various sizes of AD plants (which can help them easily repay the loans, grants they have acquired) apart from the compensation payments the scheme offers.

It is known that economic interests and incentives are not the only factors that farmers consider when deciding whether or not to participate (Siebert *et al.*, 2006). It has been found that securing farmers' independence is essential for reaching high participation rates (Schenk *et al.*, 2007). Therefore, the scheme presented to the farmers included the option of retaining the ownership of the plant or to have it managed by a power supply company to avoid the hassle and complexity of management and operation of the plant. The payment attribute was included to determine the WTA of the farmers to participate in potential schemes. This provides an insight into how farmers trade-off the changes in land management activities required by the schemes for the provision of climate regulation services.

A detailed description of the attributes and levels is presented as follows:

a. Plant generating capacity

This attribute was described as the power generating capacity of the AD plant. The generator capacity determines the energy generated by the plants to meet the farm energy needs and the cost of investment. It also represents the monetary benefits the farm will have because of the income saved by using energy generated and income made by exporting the energy to the national grid. The generation capacity scales can range between a few kWs to several MWs depending upon the amount of feedstock (animal slurries and other organic feedstock) available (Tranter *et al.*, 2011). From the review of literature and existing case studies it was identified that before installation of an AD plant it is important to establish the expected capacity of the plant. The capacity of the plant is determined by the size and livestock number on the farm. It was assumed that the farmers will consider the capacity of their farm to provide enough manure and feedstock before choosing the levels of this attribute. A wide range of generator capacities were used and defined into four levels; the first two levels were for farmers who might prefer lower generator capacities for on-farm ADs. These farmers were assumed to manage/own small scale farms with fewer livestock units and farmers who would prefer to have OFAD rather than CAD. The other two levels were for higher generator capacity plants and were targeted towards farmers with larger farms and higher livestock units. This range of generating capacities could also be translated into on-farm AD (OFAD) plants or centralised AD (CAD) plants, depending on the size of the farms managed by the farmers and the potential revenue generated by the plant. It was also expected that even small scale farmers might opt for higher generator capacity plants if they are willing to share CAD with the neighbouring farms.

b. Distance

This attribute represented the distance of the AD plant from the participating farm. The levels of this attribute were chosen to present the respondents with options of having an OFAD or a shared CAD plant. The smaller farm holders can opt for sharing the energy generation and the benefits with the neighbouring farms. CADs have proved quite successful in Denmark (Wilkinson, 2011) especially with financial incentives provided by the government. However, the farmers were also informed that increased distance of the AD plant from the farm also incurs additional transportation costs in order to transport the manure and feedstock to the plant.

The expectation here is that the farmers would respond to this attribute according to the farm size and livestock unit numbers they manage. They would also consider the costs and benefits associated with having an OFAD or CAD. This attribute will help to identify the preferences of farmers for OFADs or CADs. The estimations of this attribute will reveal if policy schemes should be designed for OFADs or CADs and the scale of the farmers these schemes should be targeted to.

c. Technical Assistance/Training

Available studies on existing AD plants suggest that farmers have in the past faced technical problems during the operation and management of the plant. Due to lack of technical assistance and knowledge, it becomes difficult for farmers to solve any mechanical issues that can be easily handled otherwise. Some AD owners have mentioned that it takes time to get trained and used to of all the mechanical and technological components of these plants. Therefore it is assumed that including technical assistance/training will help to overcome these barriers. This attribute was one of the two qualitative attributes with two levels. The levels were labelled as ‘Yes’ for the option of provision of technical assistance/training and ‘No’, if the farmers did not think of it to be important.

d. Plant ownership

Plant ownership involved options for the farmers regarding their farm operation and management. This attribute allowed the farmers to choose between managing the AD plant or to hand it over to a power supply company for its operation and management. Therefore, this attribute was defined with two levels, 'prefer ownership of the plant' or 'prefer to have it managed by a power supply company'. The first level provided the farmers with the opportunity to keep all the benefits from the plant to themselves, and required them to be responsible for the full management and operation of the plant themselves. However, the second level provided the farmers with an opportunity to participate in the scheme; without being involved in the complexity of the management and operation of the plant by handing over the plant to a power supply company.

e. Length of Agreement

Length of contract, binding the participants for a certain period of time, can have a significant role in the decision making process. The respondents for this study were provided with a wide range of levels for this attribute; 2, 5, 10, 20 years and the aim was to investigate its impact on the respondent's decision to participate.

f. Compensation payments

In order to estimate the WTA payments of the various attributes of the payment scheme, a monetary attribute related to the payment level was included. Designing a cost-effective payment scheme requires information on the minimum WTA farmers would require for carrying out the suggested changes. For policy makers, compensation is an incentive to encourage farmers to participate, and they attempt to pay appropriately to ensure their participation in the payment schemes.

This attribute will help this study to evaluate preferences of the respondents and how much it influences their participation decision. The compensation amounts were offered as 'per hectare' payments which is how farmers normally receive payments for PES schemes by government or other organisations.

Table 5.1: Description of attributes and levels for the mitigation payment scheme

Attributes	Description	Variables	Levels				Coding
Generator Capacity	The capacity of the plant to generate electricity (kW/MW)	GCAP	20kW	50kW	1MW	2MW	Linear specification
Distance	The distance of the plant from the farm (km)	DIST	< 1	~ 5	10	15	Linear specification
Technical Assistance	whether they would like technical assistance/training provided with the programme	TECH	No		Yes		Dummy coded No = 0, Yes=1
Length of agreement	The minimum contract length they prefer (Years)	LOA	2	5	10	20	Linear specification
Plant ownership	Suitable option of receiving the benefits and ownership of the plant	OWN	Prefer to own the plant		Prefer the plant to be managed by a power company		Dummy coded Own =0, power company =1
Compensation (£/ha)	Compensation payments for the total farm size (£/ha)	COMP	10	25	50	75	Linear specification

5.4. Experimental Design

After identifying the attributes and levels of policy scheme, an experimental design was constructed in order to generate the choice cards with different combinations of choice attributes and levels.

For this study, in order to generate the choice cards with different combinations of choice attributes and levels, a full factorial design was produced first. The total number of choice sets resulting from this was $4^4 + 2^2 = 260$. This large number of combinations, was considered not feasible to be used, therefore, an orthogonal fractional factorial design was generated using Ngene 1.0.2., which resulted in 36 choice sets. Since this is quite a large amount of information to be presented to one respondent, a blocking strategy was employed to reduce the number of choice sets given to each respondent. The 36 choice sets were then blocked into 6 blocks of 6 choice sets. Using this strategy, each respondent was presented with 6 choice cards.

Each choice card offered two policy options described with varying levels of attributes along with a 'do not want to participate' alternative. Before asking the respondents to complete the choice cards, they were familiarised with all the attributes (presented above) and were made aware that achieving GHG mitigation through this scheme has associated costs. They were also informed that most of this cost can be earned back by the revenue generated through the energy production and the savings on the energy bills for both the farm and the house.

A detailed description of the questionnaire and survey design is presented in Appendix A and the choice cards are presented in Appendix C of the thesis.

5.5. Results

Mitigation payment scheme estimations involved 1974 choices elicited from 329 respondents and the estimations were carried out using Limdep 9.0 Nlogit 4.0.

5.5.1. Data organisation

The data was organised according to the levels of the attributes used in the choice experiment. The two attributes with two levels were 'dummy' coded. Therefore, *training assistance/training* was coded as 0 for without training and 1 with training included in the scheme. Similarly, *plant ownership* was coded as 0 for opting to manage the plant themselves and 1 for handing it over to a power supply company. The rest of the four attributes with four levels were specified using 'linear' coding, using the same values as presented in the CE attribute design (see Table 5.1) which were presented to the respondents.

5.5.2. Descriptive Statistics

This section provides a summary of the socioeconomic characteristics and some of the land management activities carried out at the farms. Completed questionnaires from 329 farmers were used for this analysis.

The survey sample displayed considerable heterogeneity in farm characteristics and the descriptive results are presented below:

a. Distribution of respondents:

The CE survey was conducted with an intention to include a range of farming landscapes in the UK. This scheme as described above focused on mitigation of emissions from livestock manure, therefore, it was targeted towards livestock farms pre-dominantly, however, farmers with mixed farms also showed preferences for participation if they had enough livestock manure production at the farm. Figure 5.1 shows the distribution of farmers across the various regions of the UK, most of the sample constituted of farms belonging to the North of England and Midlands.

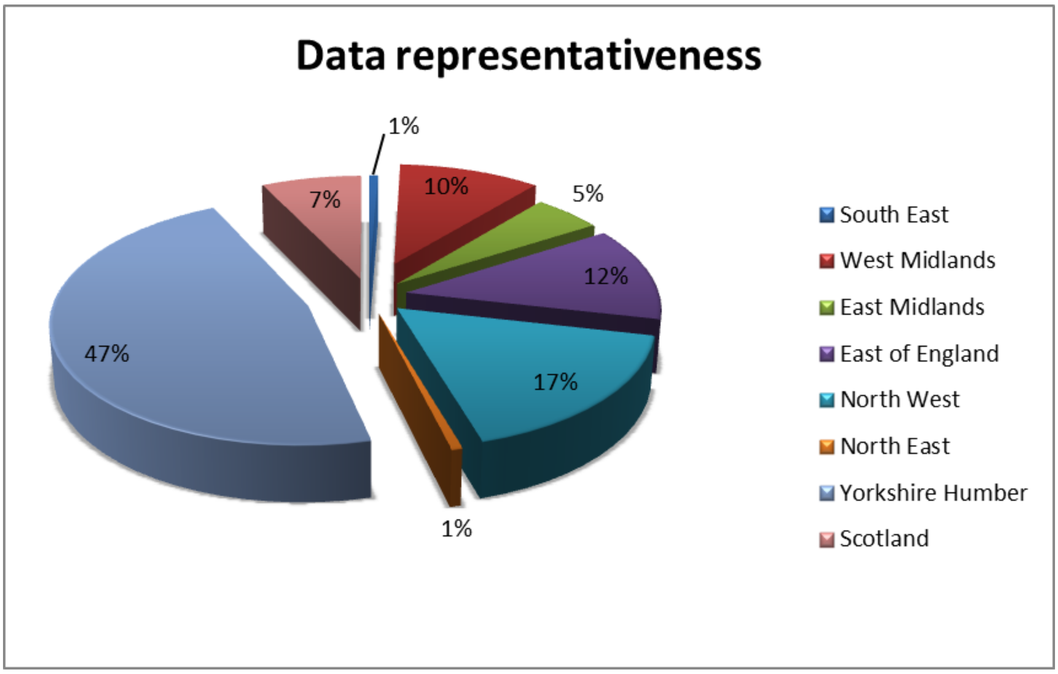

Figure 5.1 Regional distribution of the sample population

b. Age, gender, and household size:

The descriptive results revealed that the majority of respondents were middle aged to sixty years, with most of them (53%) between the ages of 41-60 years, followed closely by the respondents of the age group 17-40 years (36%). Only 11% of the respondents belonged to the older age group of 61-80 years. The male and female distribution of the respondents was 80% males to 20% females.

About 38% of the respondents had a household size of two persons, while 34% had three and 19% were with a household size of four persons. Only 7 % respondents had household sizes larger than four persons.

Table 5.2: Age, gender and household size of the respondents

	Percentage (%)	Frequency
Age (years)		
17-30	9.42	31
31-40	26.44	87
41-50	31.31	103
51-60	22.19	73
61-70	9.12	30
71-80	1.51	5
Total	100	329
Gender		
Male	80.55	265
Female	19.45	64
Total	100	329
House hold size		
1	3.04	10
2	38.30	126
3	34.04	112
4	18.54	61
5	3.65	12
6	1.82	6
>6	0.61	2
Total	100	329

c. Level of Education:

12% of the sample did not respond to this question and were considered as missing values. The survey sample showed that about 38% of the respondents hold a college degree, while 30% have been to secondary school and 18% have been to university for undergraduate and/or postgraduate degrees and only 2% had only primary education.

Table 5.3: Education level of the respondents

Level of Education	Percentage (%)	Frequency
Missing	11.55	38
Primary school	01.82	6
Secondary school	30.70	101
College	37.69	124
Undergraduate	15.20	50
Postgraduate	03.04	10
Total	100	329

d. Ownership of the land, farm size and farm income:

The survey sample shows that about 80% of the farmers owned the farmland. The farm sizes were noticed to be quite varied, the mean (139 ha) biased heavily upwards (120 ha median) with most of the farmers (77%) being in the range of 10-200ha. Most of the farmers (30%) had farm income in the range of £31,000-£60,000 and above £90,000 (29%).

e. Land use and livestock types:

Land use was typically heterogeneous within the farms with 54% of the farms being mixed farms (containing both arable and grasslands), while 41% farms were pre-dominantly grasslands. Only a small percentage of the sample (5%) managed only arable farms. The arable farms varied into root crops, cereals, oilseed rape and other vegetable farms. Mixed animal farming was very common: 64% of the farms had sheep along with dairy cows and cattle while 34% had only dairy cows and cattle. Since, this scheme was targeted to livestock farmers; most of the farmers who opted to participate in the CE for this scheme had pre-dominantly dairy and cattle farms.

Table 5.4: Farm ownership, farm size and income from the farm

	Percentage (%)	Frequency
Farm ownership		
Tenant	19.45	64
Own	80.55	265
Total	100	329
Farm size (ha)		
10-100	35.87	118
101-200	41.34	136
201-300	20.67	68
301-700	1.82	6
701-809	0.30	1
Total	100	329
farm income (£/annum)		
£6,000-£30,000	14.89	49
£31,000-£60,000	30.09	99
£61,000-£90,000	25.84	85
>£91000	29.18	96
Total	100	329

Table 5.5 Land use and livestock types of the farms

Livestock types and land use		
	Percentage (%)	**Frequency**
Livestock type		
Sheep with dairy and cattle	63.53	209
Dairy and Cattle only	36.47	120
Total	100.00	329
Land use type		
Arable	4.56	15
Grassland	41.03	135
Both	54.41	179
Total	100	329

5.5.3. Parameter Estimates of choice models

The parameter estimations for this study were done using Conditional Logit, Random Parameters Logit and Latent Class models. A detailed account of the characteristics of and differences between the various logit models is presented in Chapter 3 of this thesis.

a. Estimates of CLM

The basic *Conditional Logit model (CLM)* was specified so that the probability of selecting a particular alternative was a function of attributes and the alternative specific constant (ASC), which had a value of 1 if the 'do not want to participate' option was chosen and 0 if either of the other alternatives was chosen. The estimates show (Table5.6) that all attributes except the plant generator capacity (GCAP) have significant utility coefficients and the signs of the coefficients are as expected. The results show that respondents prefer to have on-farm anaerobic digestion plants with availability of technical assistance/training, with short term contracts, and avoiding interference of any power company for the plant management. The negative coefficient values for all attributes imply an aversion to undertake the mitigation options specified*;* however, the positive and significant compensation attribute shows that farmers are more likely to participate when a scheme offers higher compensation other things being equal. Interaction terms were also introduced between mean estimates of the utility parameters and farm/farmer characteristics with the choice data in the CLM. The assumption was that this will help to explain the effect of socioeconomic characteristics on preferences. The *conditional logit interaction (CL-int) model* was estimated for all the characteristics from the survey data. After extensive testing of various interactions with all the farm/farmer characteristics, the variables with significant coefficients were farmer's age (AGE), farm income (FINC), farm size (FSIZE) and number of livestock units (LSU). The interactions show that farms with lower farm income have a stronger preference for having the AD plant close to the farm than other farmers. It also revealed that younger farmers and farms with larger farm size require lower payments per hectare and farms with larger number of livestock units are less averse to long contracts.

Overall the results imply that farmers are willing to trade off for changes to management and compensation amounts.

Table 5.6 Parameter estimates from CL and CL-int models

Model	CLM	CLM-int
Loglikelihood	-1615.02	-1598.83
Pseudo-R^2	0.17	0.18
AIC[4]	1.64	1.63
BIC[5]	1.66	1.66
Attributes	**Coefficients (SE)**	**Coefficients (SE)**
GCAP	-0.0000 (-0.0000)	-0.0000 (-0.0000)
DIST	-0.0705*** (0.0074)	-0.0614*** (0.0091)
TECH	0.1287* (0.0752)	0.1255* (0.0756)
OWN	-0.9058*** (0.0815)	-0.4936** (0.1604)
LOA	-0.0322*** (0.0056)	-0.0568*** (0.0103)
COMP	0.0295*** (0.0015)	0.0382*** (0.0056)
ASC	-1.2016*** (0.1365)	
AGE*COMP		-0.0003** (0.0001)
FINC*DIST		-0.0001* (0.0005)
FSIZE*COMP		0.0042** (0.0001)
FSIZE*OWN		-0.0031** (0.0010)
LSU*LOA		0.0001** (0.0000)

*, **, *** indicate statistic significant at 5%, 1%, and 0.01% respectively

b. Estimates for RPL

Since CLM assumes homogeneous preferences across the respondents, *Random Parameter Logit (RPL) models* were specified to account for the taste heterogeneity of individual preferences and enhance the accuracy and reliability of the estimates.

The utility parameters for all the attributes were specified as random using *normal* distribution except for compensation which was specified with *log normal* distribution. This sensitivity analysis revealed that all attributes except

[4] AIC stands for Akaike information criteria

[5] BIC stands for Bayesian information criteria

compensation (COMP) had significant standard deviations. In the final estimations all the random attributes were specified using a normal distribution. The results (Table 5.7) show that RPL model was statistically significant with R^2 value of 0.26 and reveals unobserved heterogeneity for the 5 random attributes with significant standard deviations.

The RPL results reveal all attributes were highly significant with highly significant standard deviations indicating that these are indeed heterogeneous in the population. On average the results suggest that farmers display an aversion to higher levels of the attributes and the RPL model shows a similar trend as the CLM. The results also reveal that farmers would require higher levels of compensations for participation in scheme which requires the adoption of intensive measures.

The RPL provided a good overview of the mean effects over the population, but it is difficult to use it for analysing the patterns in the preferences (Broch and Vedel, 2012). Thus, to further account for this heterogeneity in preferences and to divide the respondents into groups with similar preferences, the *Latent Class (LC) model* was estimated.

c. Estimates for LCM

LC model also captures taste heterogeneity from different classes, each class being unique and thus accounting for heterogeneity (see details in Chapter 3). The selection of the model with appropriate number of classes which best describes the data was based on its ability to provide interpretative simplicity, statistical criteria for model fit along with analyst's judgement (Boxall and Adamowicz, 2002; Scarpa and Thiene, 2005; Swait, 1994). The model for this scenario was estimated over 2, 3 and 4 classes; however, the 4 class model did not converge. The log likelihood and R^2 values increased while AIC and BIC decreased from the 2-class to the 3-class model, thus implying that the 3-class provided a better fit. The results as presented in Table 5.7 reveals that segment-3 was associated with 43% of the sample population while segment-1 and segment-2 were associated with 34% and 23% respectively. The trend as shown in the CLM can still be seen in the LCM, however, LCM provided sufficient improvement relative to the basic CL, CL-int and RPL models in predictive capability (R^2) to justify this increased complexity. There is a general aversion for most of the scheme attributes except the availability of technical training/assistance and compensation amounts. Segment 1 shows the strongest aversion towards all the attributes out of the three segments. Though the results from all the model estimations do show that provision of technical assistance has been preferred by most of the sample population, however, the LCM revealed that segment 1 includes the population group who show an aversion to this attribute. Segment 2 shows a similar trend as the CL and RPL models, i.e. showing an aversion to most of the attributes but preferring the provision of technical assistance. However, segment 3 consists of the farmers who display a positive response towards most of the attributes. Hence, they prefer to have longer contract terms for on-farm AD plants with the provision of technical assistance.

d. ASC (status quo) consideration

For the current study the CE was designed such that respondents had the option of not selecting either of the two policy alternatives presented to them i.e. do not want to participate and had no associated compensation. Therefore, a status quo constant was added in the model estimations. This constant is generally added to represent the non-attribute reasons for selecting an attribute.

It was observed in the model estimations that the ASC has quite high negative values, which reveals that there is very strong aversion to status quo or a strong preference to move away from status quo. However, most of the coefficients of the attributes also show reluctance to levels of changes in their current way of agricultural management.

Therefore, to further explore this effect for this research, a model without ASC was also estimated. The welfare calculations revealed highly negative compensation estimates suggesting that farmers are willing to pay to participate, which seemed quite unrealistic. There has been a great deal of debate and arguments about whether to use ASC constants in valuation estimates, with some studies deciding not to use it in WTA estimations because of potential bias due to yea-saying concerns (Adamowicz *et al.*, 1998; MacDonald *et al.*, 2011). Therefore, it was decided to exclude ASC estimates from the welfare calculations carried out in Chapter 7. The 'no constant' model estimations results are presented in Appendix B for reference.

Table 5.7 Parameter estimates from RPL and LCM models

Model	**RPL (5 random attributes**		**LCM (3 CLASS)**		
Loglikelihood	-1601.98		-1486.24		
Pseudo-R^2	0.26		0.31		
AIC	1.63		1.52		
BIC	1.66		1.66		
Chi squared	1133.3		1364		
Degrees of Freedom	11		23		
			Segment 1	**Segment 2**	**Segment3**
Attributes	**Coefficient (SE)**	**Standard deviation**	**Coefficient (SE)**	**Coefficient (SE)**	**Coefficient (SE)**
GCAP	-0.0000 (-0.0000)	0.0005*** (0.0001)	-0.0001 (-0.0001)	-0.0004*** (0.0000)	0.00005 (-0.00005)
DIST	-0.0408*** (0.0108)	0.1242*** (0.0138)	-0.1300*** (0.0274)	-0.2097*** (0.0156)	-0.0106 (-0.0079)
TECH	0.3599*** (0.0909)	0.5967** (0.1964)	-0.4455* (0.2311)	1.0529 *** (0.1563)	0.2246** (0.00845)
OWN	-0.803*** (0.09896)	0.5659** (0.2039)	-5.9656*** (0.9441)	-1.2982*** (0.1433)	-0.6068*** (0.0825)
LOA	-0.0185** (0.0071)	0.0637*** (0.0097)	-0.4399*** (0.0649)	-0.0292** (0.0105)	0.0301*** (0.0067)
COMP	0.0477*** (0.0024)		0.0700*** (0.0081)	0.0271*** (0.0031)	0.0267*** (0.0020)
ASC			-8.1142*** (1.2213)	-0.8734*** (0.2340)	-1.2368*** (0.1939)
Percentage			34%	23%	42%

*, **, *** indicate statistic significant at 5%, 1%, and 0.01% respectively

Post-hoc analysis of individual-specific segment membership probabilities in the LCM using farm/farmer characteristics as individual-specific variables was used to investigate the suggested segment association of each individual (Wedel and Kamakura, 2000). The majority of the heterogeneity was not observable. However, the estimations (Table 5.8) revealed that farm income, age, and livestock units are the most important determinants of segmentation in the sample. There is a higher probability of belonging to segment-1 if farmers have a low number of livestock units while segment-2 farmers are mostly in the older age group and with low farm incomes.

Table 5.8 Explanation of the Individual Segment specific probabilities with socio economic characteristics

	Segment 1	Segment 2	Segment 3
CONSTANT	0.4581 (0.9586)	-2.1775* (1.0871)	Fixed
Gender	-0.0582 (0.3240)	-0.0783 (0.3793)	Fixed
Ownership	0.1274(0.3422)	0.1117 (0.4077)	Fixed
Farm income	0.0000034 (0.0000)	0.000024* (0.0000)	Fixed
Farm size	0.00158 (0.00178)	-0.0011 (0.0020)	Fixed
Education	0.0976 (0.1140)	0.0425 (0.1245)	Fixed
Age	0.0054 (0.0129)	0.0326** (0.0145)	Fixed
Household size	-0.1263 (0.1347)	0.1603 (0.1447)	Fixed
Livestock units	-0.0037** (0.0013)	-0.0020 (0.0013)	Fixed
Percentage	34%	23%	42%

*, **, *** indicate statistic significant at 5%, 1%, and 0.01% respectively

5.6. Minimum marginal WTA estimates

The results of the model estimations suggest that there is considerable taste heterogeneity within the farmers. The results of the LCM suggest that the sample significantly comprised of three classes. An examination of the log-likelihood values indicate that LCM model provided an improvement in the fit over the CL and RPL models. It is also clear from the results that 42% of the sample population belong to the third segment while the rest are divided between the first and second segment.

The results of the overall marginal WTA estimates for each of the model (Table 5.9) show that the highest WTA estimates of £85.15 are revealed for the members of segment-1 of the LCM for retaining the ownership of the digestion plant themselves. It was also observed that within each model and each segment the highest WTA estimates are for the 'plant ownership' attribute. As discussed in the results section the model estimations revealed that farmers preferred to keep the ownership of the plant to themselves. Higher WTA estimates for this attribute, shows that they prefer retaining the monetary benefits (both in terms of compensations and revenue).

Since, LCM proved to fit the data better the parameter estimates from the LCM model were used to calculate individual-specific estimates (Train, 2003). These estimates can then be used to calculate individual-specific WTA values which give a distribution of WTA values for each attribute. Segment-specific estimates of minimum WTA values for particular attribute were calculated to produce estimates of respondents-specific minimum WTA values.

Table 5.9 WTA estimations from the choice models for the mitigation payment scheme (in GBP/year)

Attributes	CL	CL-int	RPL	LCM 3 segment		
				Segment-1	**Segment-2**	**Segment-3**
			Mitigation scenario			
Generator capacity	0.00	0.00	0.00	0.002	**0.02*****	-0.002
Distance	2.39	1.61	0.86	**1.86*****	**7.73*****	0.40
Technical Assistance	-4.36	-3.28	-7.54	**6.36***	**-38.81*****	**-8.38****
Plant ownership	30.67	12.91	16.83	**85.15*****	**47.85****	**22.65*****
Length of Agreement	1.09	1.49	0.39	**6.28*****	**1.08****	-1.12

*, **, *** indicate statistic significant at 5%, 1%, and 0.01% respectively

Negative (-) minimum WTA values mean that the respondents do not require any compensation for adopting the suggested changes.

Kernel density plots provide a useful illustration of heterogeneity within the WTA results. These graphs can be helpful in presenting comparisons of segment memberships. A description of the density estimates for the WTA estimations for each attribute follows:

Generator Capacity:

Figure 5.1 shows that all three segments have very low WTA values for this attribute and only segment-2 farmers show some significance consideration to it. Segment-3 farmers do not require any compensation for this attribute. Despite this attribute actually representing the size and the revenue generated by the plant, still it appears the farmers did not pay much attention to this attribute and the results show that this attribute does not have a significant effect on the participation behaviour of more than 50% of the sample population.

Distance:

All three segments have positive compensation values for this attribute, however, only the first two segments show positive WTA values, implying that they require compensation values for this attribute to be included in the scheme, while segment 3 farmers are shown to be not affected by this attribute. It is also clear from the estimations that overall the sample prefers to have AD plants closer to their farms. This can be due to the cost of transportation of manure associated with the increase in distance between the plant and the farm.

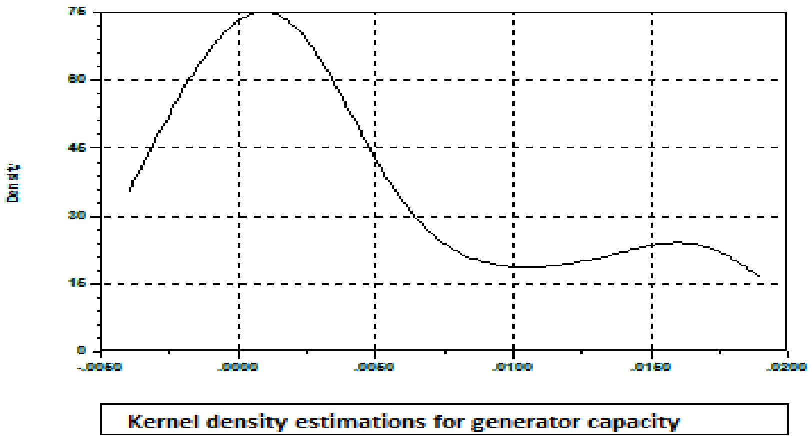

Figure 5.2 Distribution of individual-specific minimum WTA for generator capacity of AD plant

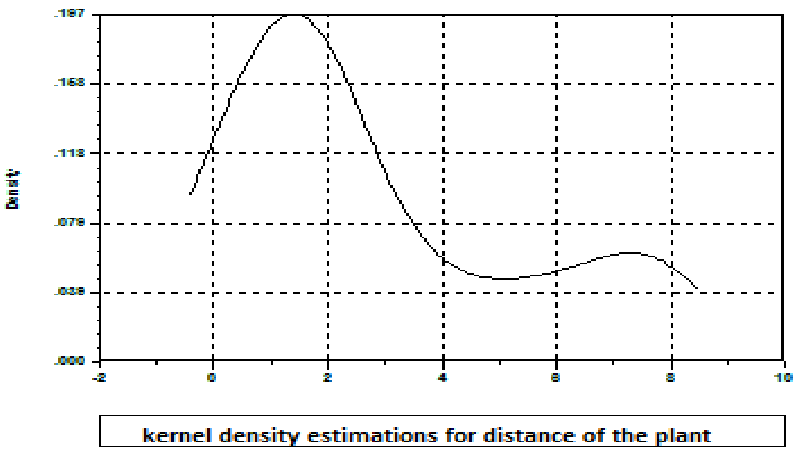

Figure 5.3 Distribution of individual-specific minimum WTA for Distance of AD plant from the farm

Technical assistance/ training

All the segments show significant values towards this attribute, showing that they prefer to have this attribute included in the scheme (Figure 5.4). The first peak in the graph represents segment-2 and shows the strongest preference for this attribute. The literature (as discussed in section 5.3) identified lack of technical assistance/training as one of the major reasons for the closure of past AD plants in the UK, as the farmers did not have enough technical skills to properly manage and operate the plants themselves.

Plant ownership

All segments show very strong significance for this attribute and all of them require the highest compensation values for this attribute. This displays that farmers prefer to avoid the hassle of dealing with external companies and prefer to retain the revenue net-benefits to themselves. The second peak in Figure 5.5 represents segment 1 which have the highest compensation for this attribute.

Length of agreement

Figure 5.6 illustrates that farmers of segment 1 and 2 have compensation amounts in the positive range of the graph. The highest peak is for segment-1, requiring the highest compensation amounts increasing the length of agreements. Segment-3 farmers however, do not require compensations for this attribute. It is clear from the estimations that most of the sample population prefer short term contracts for this policy scheme.

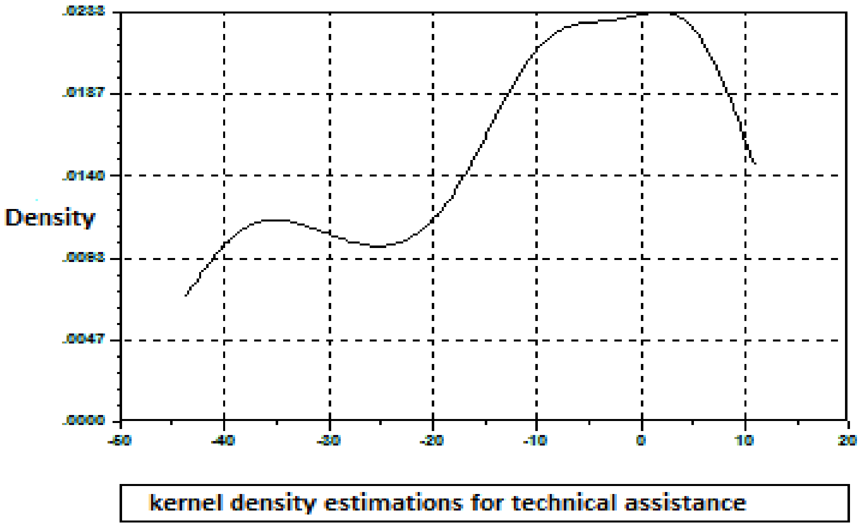

Figure 5.4 Distribution of individual-specific minimum WTA technical assistance/training

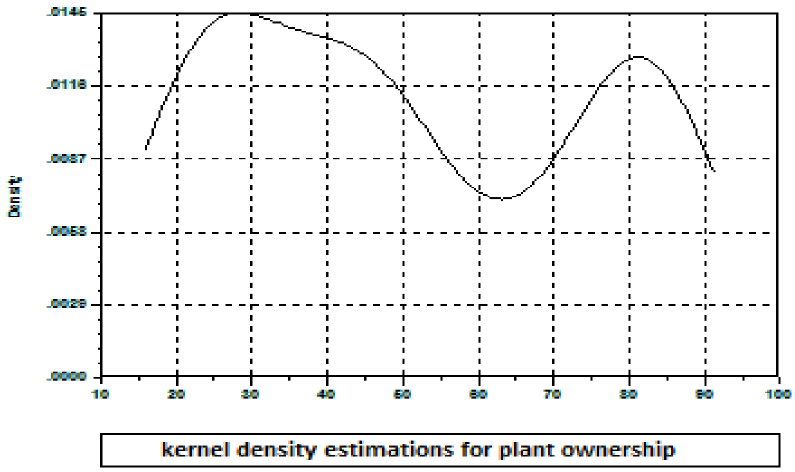

Figure 5.5 Distribution of individual-specific minimum WTA Plant ownership for AD plant management

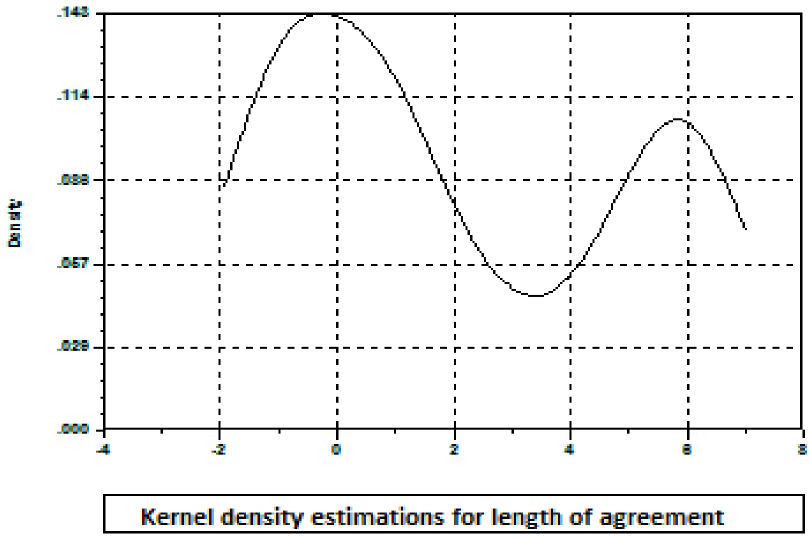

Figure 5.6 Distribution of individual-specific minimum WTA length of agreement of the scheme

5.7. Discussion

Although agroecosystems are major contributors to the UK's national annual emissions of GHGs, it is also clear that this ecosystem can also help to mitigate these emissions. In this regard a technology based policy scheme was designed to reduce the methane emissions from livestock. This policy was specifically designed to identify the target groups in the pre-dominantly livestock farming sector. This study contributes to the literature on estimation of economic costs to the government of emission reductions from UK livestock farms by looking into the scope of mitigating methane emissions by designing a potential payment scheme. The hypothetical payment scheme was developed with scheme attributes suggesting different levels of changes in the management activities. In compensation for undertaking these changes the farmers were offered various levels of annual payments.

A CLM, RPL, and LCM were used to analyse the data. In common with previous studies (For example, Beharry-Borg *et al.*, 2012; Christensen *et al.*, 2011; Ruto and Garrod, 2009) the farmers were found to show heterogeneous preferences for different land use management activities. The results suggested that farmers generally show aversion to drastic changes in their land use management activities but they can be encouraged to adopt some activities by providing the appropriate level of changes and compensation incentives. Results generally imply that most farmers would prefer to participate in schemes with flexible and less restrictive measures. The importance of scheme flexibility has also been suggested by Ruto and Garrod (2009) and Wynn *et al.* (2001). Ruto and Garrod indicated that generally farmers participating in AES across Europe are willing to trade-off 6-10% of their current payments for flexibility over measures or land attributes and demand higher payments for attributes like increased paper work and increased contract duration.

The basic CL model revealed that all the attributes except the anaerobic plant generator capacity significantly influences farmers decision to voluntarily participate in the payment scheme. The results implied that on-farm anaerobic digestion plants are likely to be attractive for larger scale farms with higher number of livestock units conditional upon the combinations of distance of the plant, availability of technical assistance, length of agreement, plant ownership, and payments per hectare. Furthermore, the analysis of the preferred three segments Latent Class model indicated a general aversion to most of the attributes except the provision of technical assistance/training. The segment membership revealed that segment-1 farmers are the most averse while segment-3 farmers are more willing to participate and prefer OFADs with longer contracts.

Including the socio-economic interactions in the CL model provided information about the behaviour of the farmers. This model indicated that farmers with higher farm income prefer to have the AD plants very close to the farm, which can be due to avoid the hassle and costs associated with transport of manure to the plants. The analysis also revealed that lower compensations are required by younger farmers and larger farms while farmers with larger farm sizes have higher preference for retaining the ownership of the plant. Another determinant was the number of livestock units, which has a positive influence over the farmers preference towards length of agreement i.e. farms with higher number of livestock units are less averse to longer contracts.

Overall the results show a preference for short term contracts, which is in accordance with Ruto and Garrod (2009). However, considering the associated investment costs and the requirement of longer time period to achieve the required GHG reduction, it seems more appropriate to have long-term schemes. Further investigations using the Latent class model revealed that one segment of farmers were less averse to long term contracts which were identified to be farms with higher number of livestock units. Hence, this helped to identify the target group to achieve the required long-term commitments.

Estimations of the relationship between individual specific segment membership and socio-economic variables provided further understanding of the segmentation of the sample. It indicated that farm income, age, and livestock units were the main determinants of farmers' segmentation. Segment-1 farmers having smaller number of livestock units while segment-2 comprised of older farmers and farms with higher farm incomes.

The descriptive statistics presented in the subsection 5.5.2 show that the sample consists mostly of remote farms belonging to the North of England and Midlands. Average age of UK farmers is 59 years (DEFRA, 2012) while the sample showed an average of 45 years. The statistics also revealed that 80% of the farmers owned their farms (while in the UK agriculture sector 63% are owners of the farms). It was also shown that the average farm size for the sample (140ha) was higher than the UK average of 77ha (DEFRA, 2012), revealing that most of the farms included in the sample are large farms.

The CE results reveal that there is a higher possibility of participation in payment schemes by younger farmers, large farms with high farm incomes, and large number of livestock. The sample profile also shows similar characteristics, making the assessment of implementation of payment schemes more favourable. Furthermore, since the sample collected represents mostly remote farms from the northern parts of England and Midlands, these results cannot be effectively generalized to the UK. This suggests that it is important for policy makers to take complete profile of the target groups into account for designing effective policies.

The WTA estimates revealed that the ownership of the anaerobic plant has been given significant consideration by the farmers and they prefer to keep the ownership of the plant to themselves, avoid hassle of dealing with others, and avoid sharing the income. Further analysis of individual specific WTA estimations show that segment-1 farmers consists of the farmers which show the strongest aversion and require higher minimum compensations for participating in such schemes while the segment-3 consists of farmers which are more flexible and require lower compensation values for most of the scheme attributes.

Methodologically this study shows that CL-int and RPL models can provide useful information on main drivers of heterogeneity but LCM was required to show a more distinct distribution of that heterogeneity. As in this study the sample was categorised into three segments, each showing a distinctive behaviour towards the scheme design.

Understanding how preferences of farmers vary across the population, policy makers can be in a better position to design such schemes. Linking the recommended management activities to the WTA compensation values, can help to understand how the target farmer population will behave towards different levels of required changes. By considering the heterogeneity of farmers, it has been shown that there is a potential of attracting farmers at the lower WTA spectrum by keeping some flexibility in the scheme designs. The findings reveal that livestock farmers can be attracted towards centralised AD plants easily as they consider it to be a less expensive option with less initial capital costs and inputs.

5.8. Conclusion

This chapter reported results of a CE study to investigate how farmers' trade-off the changes in land management practices required for the provision of GHG mitigation.

An in-depth understanding of the farmers' behaviour and preferences can provide useful information towards developing and designing new agri-environment schemes which ensure sufficient participation by the farmers. The results of the estimations suggest that the possibility of attracting farmers to mitigate GHG emissions exists but requires higher compensation payments. AD plants have not been very popular in the UK as compared to some of the mainland European countries. This study, looking at the feasibility of a scheme which requires the adoption of AD plants, provides an insight into the behaviour of farmers towards various scales and types of AD plants. This can help policy makers to design policies and AD plants according to the preferences of farmers.

The results reveal that small scale farmers show very strong aversion to AD plants. This is potentially attributed to the fact that AD plants have very high associated capital costs. This can help to address the issue of AD plant closure in the UK by helping farmers to better understand how to set up plants which are better suited to their farms and are more sustainable over longer time periods. The study identified that younger farmers, larger farms, and farms with more livestock units can be potential target groups for effective implementation and targeting of mitigation schemes.

This study contributes to the literature on climate change mitigation for agricultural ecosystems. The survey reveals that farmers, though willing to participate in either small scale OFADs or CADs, do not have the required capital investments. This study shows in addition to favourable governmental regulations (in terms of loans, subsidies, funding grants etc.) simplistic plant designs and monetary incentives can help to attract farmers towards setting up plants for generation of renewable energy.

In summary, this chapter provides useful information to address the climate change mitigation provided by UK livestock farms by designing cost effective schemes for farmers. This can encourage farmers to make desirable changes in their land use activities. The study identified target groups by providing segmentation of survey respondents according to their characteristics and associating it with their willingness to accept values. Further work linking the spatial attributes and distribution to this segmentation can help to identify the target areas for effective implementation of the policies.

The key findings of the study provide a basic insight into the preferences of farmers and provide a further possibility of carrying out a cost-effectiveness analysis in terms of carbon abatement costs for each farm. This will help to provide information regarding the potential costs of achieving GHG mitigation. The cost-effectiveness analysis along with the spatial distribution of costs will be presented in Chapter 7.

Chapter 6 Investigating farmers' preferences for payment schemes to promote carbon sequestration

Abstract

This chapter provides details of a CE study to investigate arable farmers' willingness to participate in a policy scheme designed to enhance carbon sequestration service provided by the UK farmlands. This study was done in conjunction with the study presented in the preceding chapter of this thesis. It provides an extension of the CE work done for the mitigation policy scheme (Chapter 5). As highlighted in the previous chapter, the respondents opted for the preferred payment scheme according to their farm types and a total of 115 responses were collected for this policy scheme. Most of the respondents, who opted to participate in this scheme, have either pre-dominantly arable farms or mixed farms, with large area of arable land. The responses for this scheme were also analysed using three discrete choice models. The estimations presented an overall aversion to drastic changes in land management activities. Unobserved heterogeneity was identified across the study sample however, even latent class model was not able provide a very distinct categorisation of the sample. In line with the results of the mitigation payment policy, the estimations for this model also revealed that farmers prefer lower level of changes in the land management activities. The marginal willingness to accept estimations illustrate that they are willing to adopt changes like conversion of arable land to grassland and afforestation. However, higher compensations will be required for the adoption of conservation ploughing and extensive grazing.

6.1. Introduction

This chapter presents the second payment scheme of the CE study of this thesis. It provides the details from the investigation of arable farmers' participation behaviour in a carbon sequestration payment scheme. This study includes the investigation of preference heterogeneity of farmers for scheme attributes and factors affecting their land use and participation decisions. An account of payment schemes and participation in payment schemes in general has been presented in Chapter 5, Section 5.1., followed by some evidence from literature about factors affecting the preferences of farmers in Section 5.2. Therefore, this chapter only focuses on the specific existing knowledge of the participation behaviour related to arable farmers.

Agricultural land is a very actively managed ecosystem which provides food, fuel and fibre for human use along with various other use and non-use services. It plays a substantial role in maintaining global climate regulation especially the carbon cycle. Agricultural land is considered to contain about 12% of global terrestrial carbon (Dixon *et al.*, 1993). Above ground vegetation including forests act as carbon sinks; however, soil can store much more carbon than the vegetation depending on the land use (Milne and Brown, 1997). The storage of carbon in the soil is a global issue and it requires appropriate policies to address it in a sustainable way. Many agricultural practices can contribute towards enhancing carbon sequestration in agricultural land such as reduced tillage, crop residue incorporation, using cover crops, appropriate application of manure, and afforestation. The amount of carbon stored is dependent on the type of land use (John et al, 2005). In view of these facts, land management can be moderated to enhance carbon-sequestration in agricultural land at ecosystem-level by adopting changes in land use.

There is a need to develop appropriate and feasible land use management to enhance the carbon storage capacity of agricultural land. Various conservation programmes have been outlined with the aim to enhance or conserve different environmental services. These programmes have mostly been developed for reducing soil erosion, improving water quality, enhancing crop productivity, conserving biodiversity, forest conservation etc. The programmes include The Conservation Reserve Program (CRP) in the US (introduced in 1985), the Permanent Cover Program (PCP) in Canada (in 1989), two policies (in 1992) under the EU Common Agricultural Programme (CAP) first involving policies to set aside agricultural land and the second involving afforestation to reduce the wood shortage problem in the EU (Chen *et al.*, 2009), PSA programme in Costa Rica for forest conservation, afforestation and sustainable forest management (Zbinden and Lee, 2005). These policies enrolled farmers by providing them with payments for converting croplands to grassland, forest or other conservation uses through contracts typically lasting 10-20 years. In China the Grain to Green project (1999) was developed for conversion of arable land to grasslands and forest. This project was started to reduce soil erosion which was affecting the water resource. Similarly, Parks and Hardie (1995) provide an account of a payment scheme for afforestation of marginal agricultural lands, developed on the pattern of the US CRP using four scenarios targeted towards croplands and pastures. Agri-environmental schemes have also been introduced in the UK and include the Environmentally Sensitive Area (ESA) scheme and Countryside Stewardship (CS). These schemes have been designed for farms across the UK, to maintain and protect landscapes and biodiversity by adopting environmentally friendly farming practices.

The literature on payment scheme participation for agricultural land use considers the effectiveness of payment schemes. Being voluntary in nature, their effectiveness is dependent on the willingness of the farmers to participate. Land managers have various motivations for participation (non-participation) in such schemes and determining these motivational factors is crucial for effective implementation. Farmers' participation has been identified to be dependent on both farm/farmer characteristics and scheme design. It is posited in the literature that farmers' participation decisions are positively affected by their attitude and behaviour with a focus on motives and values (Morris and Potter, 1995; Wilson, 1997), scheme designs being in accordance with the farming type and low associated cost (Wynn *et al.*, 2001), environmental attitudes (Dupraz *et al.*, 2003; Vanslembrouck *et al.*, 2002; Wilson and Hart, 2000), and adequate compensation considering both the associated costs and loss of income (Defrancesco *et al.*, 2008). However, drastic and labour intensive land use changes oblige the farmers towards non-participation (Defrancesco *et al.*, 2008). It is also considered important that the scheme should fit with the current farming activities (Wilson and Hart, 2000). Overall, it can be summarised that in order to attract farmers a scheme should offer compensation payments no less than the benefits foregone, at level with efforts required; stable long term funding; flexible land use management changes, and should account for the best farm management activities for a particular service to be improved or conserved. WTA for adopting the changes can provide information about the variability in farmer's requirements. This study utilizes a CE approach, which has been the preferred method for various studies (such as Beharry-Borg *et al.*, 2012; Broch and Vedel, 2012; Espinosa-Goded *et al.*, 2010; Ruto and Garrod, 2009) looking at scheme effectiveness and farmers participation. Modelling farmers' choices can help to estimate how they trade-off different scheme attribute combinations against the compensation payments.

Most of the past studies for enhancing carbon in arable land have focused on design of schemes for a single carbon sequestration activity (such as Henry *et al.*, 2009; Morris and Potter, 1995; Parks and Hardie, 1995; Plantinga *et al.*, 1999). However, the study presented in this chapter, involves the design of a payment policy involving a whole farm plan, incorporating several carbon sequestration measures together. This all-inclusive approach better assesses the relative advantage of different measures and combination of measures to achieve the required target.

The overall aim of this chapter is to investigate landowners' agri-environmental scheme preferences for enhancing carbon sequestration and to suggest scheme design for developing effective policies for attracting more arable farmers to contribute towards the UK's carbon abatement targets. This will be achieved by achieving the following objectives:

- Estimating farmers WTA requirements for the adoption of changes in land use practices through the uptake of carbon sequestration measures.
- Exploring the extent of heterogeneity in WTA requirements of farmers for a potential carbon sequestration policy and investigating whether this heterogeneity is associated with particular farm or farmer characteristics.

This chapter first provides a review of the related literature leading to the development of the carbon sequestration policy scheme and the framework adopted for this study in Section 6.2. This is followed by Section 6.3 describing the attributes and the levels defining the sequestration scheme. The descriptive statistics and the results of the discrete choice models are presented in Section 6.4. This is followed by an analysis of the minimum WTA estimations in Section 6.5 and the illustration of the individual-specific WTA values using kernel density graphs. Section 6.6 presents a discussion of the estimation results, and finally the chapter ends with a discussion of the main conclusions of the study (section 6.7).

6.2. Theory and Methods

6.2.1. Carbon sequestration through arable farms

Increasing soil carbon, not only reduces the carbon levels from the atmosphere, but also contributes towards soil fertility, improves moisture content in the soil, and improves nitrogen fertiliser use by crops and makes the soil more resilient to climatic stress (Dumanski, 2004; Johnson *et al.*, 2005; Smith *et al.*, 2007b). According to Smith (2004) recent intensive land use changes have resulted in continuous loss of carbon from agricultural lands. To enhance this stock and to capture atmospheric carbon farmers must be involved to make appropriate land use changes. Using arable land for afforestation, conversion to grassland or other non-agricultural uses can help to reduce the GHG emissions and enhance carbon sequestration (Rounsevell and Reay, 2009).

Agriculture is an important part of UK land use and according to DEFRA (2012); it makes up 70% of the total UK land area of which 36% is considered to be crop-able land. Increasing soil carbon in arable land can lead to additional benefits like increasing soil fertility, improvement in moisture retention capacity, improving the absorption of nitrogen, and reducing soil erosion by reducing soil compaction. The ability of arable land to enhance carbon sequestration has been identified by various studies (for example Follett, 2001; Lal, 2008; Smith *et al.*, 2007b; Smith *et al.*, 2008) through cropland management (ploughing methods), grazing management, forestation of arable land, and improvement of degraded land. Implementing policies incorporating such management changes often requires incentives to attract farmers. Therefore, designing payment schemes can prove to be useful in this context, as farmers can be compensated for the contribution they make to enhance the carbon sequestration service.

Though various carbon sequestration measures have been recommended in the literature, some issues around these have also been presented in Smith *et al.* (2007b). These include, additionality[1], permanence, leakage, availability of capital, transaction costs, consistency with traditional practices, and the high costs of technology, to name a few. Avoiding these issues can enhance the efficiency of carbon sequestration; therefore, potential payment schemes were identified for arable farmers which also addressed some of these issues. The proposed potential sequestration policy required farmers to adopt some land use management changes on their farms, which can help to increase the carbon storage potential of their farm. They were asked to enrol land for conversion from arable to grassland and for afforestation in addition to what they already have on their farms. This addressed the issue of *additionality* as the farmers were required to convert additional land to be eligible for compensation payments. Similarly, including

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[1] To make sure that land use change or the proposed measure achieves additional carbon sequestration to the current land use and management activities,

attributes like restrictions on grazing time periods and changes in ploughing methods, did not require the farmers to *adopt new technologies*, and hence did not lead to any high *associated costs*. *Consistency with traditional practices* was addressed by including conventional ploughing alongside conservation ploughing.

The adoption of changes in agricultural land uses by farmers requires various trade-offs. Generally, farmers consider the economic productivity of their farms, before making any conservation-based decisions. However, most of the agricultural measures for carbon sequestration also have associated secondary benefits. Carbon storage in soil can increase soil fertility (Lal, 2008), reduce erosion by the use of conservation tillage methods (Johnson *et al.*, 2005); enhance soil moisture, reduce soil compaction by improving the vegetation cover in the form of grassland; improve biodiversity; and increase the availability of grassland for feedstock for renewable energy production by adopting extensive grazing measures (Smith *et al.*, 2008).

Therefore, it can be useful to have information about the attitude of farmers towards these trades-offs and co-benefits in order to design better informed policies for achieving the climate mitigation target in the agricultural sector.

6.2.2. Study Framework

As mentioned in subsection 6.2.1., arable land has the potential to sequester carbon both in soil and vegetation. This service can be enhanced by adopting appropriate land use activities. This chapter, as highlighted previously, reports a CE study to assess how payment scheme design can influence arable farmers' willingness to participate in schemes to enhance carbon sequestration on their lands. This study was carried out in conjunction with the CE study presented in Chapter 5.

The first step was to define appropriate attributes and levels. These were selected according to their significance towards enhancing carbon storage after a comprehensive review of measures recommended in literature. A detailed account of these attributes and levels is presented in section 6.3. After selection of the attributes and the levels an appropriate CE design was generated and included in the survey questionnaire. A total of 115 face to face questionnaires were conducted (for details please refer to appendix A of the thesis) for this payment scheme scenario.

The data collected included both choice data and socioeconomic data of the respondents. This data was used to investigate the behaviour of the farmers towards a potential scheme design and to analyse the impact of different attributes and attribute levels. In order to understand the preferences better, three Logit models; CLM, RPL, and LCM were used to carry out the estimations. The CLM provides basic estimations, while RPL was used to identify the preference heterogeneity and the LCM to identify the sources of heterogeneity by providing a segmentation of the sample population. The minimum willingness to accept requirements were calculated and further analysis of individual specific WTA estimations were carried out to explain the reason behind the farmers' decisions about WTA compensations and illustrated with kernel density graphs.

6.3. Attributes for sequestration policy scheme

Significant attributes with realistic levels were selected after an intensive literature review and information from the pre-test of the study. The range of the levels was selected to represent each attribute according to the size and scale of improvement that farmers are willing to adopt.

The sequestration policy scheme, as described in section 5.2.2, was developed pre-dominantly for arable farms and required the farmers to adopt changes in their farm management activities in order to enhance the storage of carbon both in the soil and vegetation on the farm. This scheme required the farmers to assess schemes including enrolment of land for grassland conversion, afforestation, to restrict grazing, and to adopt conservation tillage. The potential payment scheme was described in terms of 6 attributes, four of which were described in quantitative terms while the other two were qualitative. The payment attribute was included to determine the WTA of the farmers to participate in potential schemes. This provides an insight into how farmers trade-off the changes in land management activities required by the schemes for the carbon sequestration service.

The assumption was that the selection of the alternatives and attributes would help to provide an understanding of the preferences of the farmers towards agri-environment schemes for enhancing carbon storage in UK arable farms.

A detailed description of the attributes and levels is presented as follows:

a. Land enrolment for conversion to permanent grasslands

This attribute required farmers to enrol a certain percentage of their arable land for conversion to permanent grassland. Permanent grassland can help to reduce the loss of carbon from arable soil due to lower soil disturbance and reduction in harvested products also enhance the carbon storage potential both in the soil and vegetation (Smith *et al.*, 2008). Carbon storage through grasslands proves very favourable as more carbon is stored in the roots, which keeps it restrained within the soil rather than released to the atmosphere (Wreford *et al.*, 2010).

The attribute was presented in terms of percentages of the total arable land the farmer managed and four levels were defined, to provide an opportunity for most of the farmers to enrol some of their land, even if they have other constrains in their farm management.

b. Land enrolment for afforestation

Afforestation on farms and agricultural landscapes has been considered an important mechanism when it comes to GHG mitigation in the agricultural sector. It has been recognised as a carbon sequestration activity approved under the Kyoto Protocol and comes under the Land Use, Land Use Change and Forestry (LULUCF) activities of the IPCC report in 2001 (Ramachandran Nair *et al.*, 2009). This attribute required farmers to enrol a certain ‘percentage’ of arable land for afforestation. The attribute was represented by four levels, providing an opportunity for both small and large scale farmers to be able to participate in the scheme by choosing lower or higher levels of the attribute.

c. Changes in grazing time

This attribute was defined for changes in livestock grazing. Intensity and timing of grazing influences the growth, carbon storage and productivity of grasslands (Freibauer, 2003; Smith *et al.*, 2007c). Under normal conditions the farmers would prefer to let their livestock graze as much as possible to increase their livestock productivity. However, lower levels of grazing are more favourable for enhancing carbon storage in grazing lands (Smith *et al.*, 2007b). Taking these facts into consideration it is important to control grazing time periods on grasslands, as long term intensive grazing can lead to both over-grazing and eventually can affect the carbon storage negatively.

Hence, this attribute was described with two levels, giving the choice between continuing intensive grazing or making a shift to extensive grazing time periods. Though extensive grazing is beneficial both for the farmer, in terms of improvement in grassland productivity, and for climate change policy makers, still it is observed that most of the farmers, prefer intensive grazing for their livestock.

d. Changes in ploughing methods

Shifting from a conventional to conservation till system can help to reduce soil erosion by reducing the disturbance in the top layers of the soil and also helps to capture carbon in the soil, by keeping the top soil covered by organic matter (Alvarez, 2005). This helps to reduce erosion and increase the carbon content of the soil (Pretty *et al.*, 2002). It was observed that farmers prefer conventional tillage as they perceive it to be a hassle free mode of ploughing.

The respondents were presented with two levels for this attribute, which required them to choose between carrying on with conventional ploughing or shifting to conservation ploughing methods. This attribute was included into the design with the assumption that the estimates for this attribute would help to provide a real insight into the preferences of farmers and what would be required at the policy design level to encourage them to adopt conservation ploughing methods.

e. Length of Agreement

Changes in soil carbon require longer time periods in order to be measureable. Hence, it seems most appropriate to have long term policies for the provision of carbon sequestration services. However, it is usually difficult to engage farmers in long term commitments. Although it has been identified in previous studies that farmers prefer short term contracts, it can also be associated with the type, size, and attitude of the farmer himself. In order to investigate this, this attribute was represented by four levels, from shorter 2 years contracts to longer contracts up to 20 years. The long term contracts can help to address the 'permanence' issue mentioned in section 6.2.1.

f. Compensation payments

Compensation amounts are an important part of any scheme design and can strongly influence the choice and participation of farmers. In order to estimate the WTA payments for adopting the scheme, a monetary attribute was included in the scheme design. The selection of the levels of the compensation attribute provides an insight into the compensation amounts that farmers would require for the overall contribution of their farm towards the provision of a service. Usually farmers are considered to be profit maximisers and in order to ensure their participation in schemes requiring changes in land use activities it is important that appropriate compensation should be allocated for the scheme.

The compensations was offered as 'per hectare' payments for the whole farm. Although the levels of payments cannot be assigned according to the actual amount of carbon sequestered, it is still important to reward the farmers according to the measures implemented and the associated productivity loss. Therefore, a wide range of levels were presented and it was also assumed that the compensation amounts selected can help to provide a better understanding of farmers' attitudes towards conservation.

Table 6.1: Description of attributes and levels for the mitigation payment scheme

Attributes	Description	Variable	Levels				Coding
Enrolment for permanent grassland	Area of land to enrol for conversion to grassland (%)	PGRASS	10	15	30	50	Linear specification
Enrolment for afforestation	Area of land to enrol for afforestation (%)	REF	2	5	10	15	Linear specification
Grazing time periods	Preferable grazing time period	GRAZ	Intensive grazing		Extensive grazing		Dummy coded, Intensive=0, Extensive= 1
Ploughing methods	Preferable ploughing method	PLOUGH	Convention al till		Conservation till		Dummy coded, Conventional= 0, Conservational= 1
Length of agreement	The minimum contract length they prefer (Years)	LOA	2	5	10	20	Linear specification
Compensation (£/ha)	Compensation payments for the total farm size (£/ha)	COMP	10	25	50	75	Linear specification

6.4. Experimental Design

The experimental design was constructed using Ngene 1.0.2., in order to produce different combinations of choice attributes and levels to be presented in each choice card.

As presented in Chapter 5, section 5.4., the full factorial design was too large to be used; therefore, an orthogonal fractional factorial design was generated. This resulted in 36 choice combinations, which were further blocked into 6 blocks of 6 choice sets, for the convenience of each respondent to be able to understand the information provided. Therefore, each respondent was presented with 6 choice cards each and a total of 6 respondents were required to complete the whole choice design.

Each respondent was presented with two policy alternatives offering different combinations of the levels along with 'I do not want to participate' (that is business as usual). During the survey the respondents were first familiarised with the attributes and the effect of adopting the changes, on their farm and carbon storage.

Detailed description of the CE design and the survey is presented in the Appendix A and the choice cards are presented in Appendix C at the end of this thesis.

6.5. Results

Sequestration payment scheme estimations involved 690 choices elicited from 115 respondents and the choice model estimations were carried out using Nlogit 4.0.

6.5.1. Data organisation

The data was organised according to the levels of the attributes used in the choice experiment. The two attributes with two levels were 'dummy' coded. Therefore, *changes in grazing time* were coded as 0 for intensive grazing and 1 for restrictive grazing. Similarly, *changes in ploughing methods* were coded as 0 for conventional tillage and 1 for conservation tillage. The other four quantitative attributes were specified linearly using the same values as presented in the CE attribute design (see Table 6.1).

6.5.2. Descriptive Statistics

This section provides a summary of the socioeconomic characteristics and land use management activities carried out at the farms. The descriptive results of 115 respondents who completed the questionnaires are presented and discussed here.

a. Distribution of respondents:

The CE survey for the study was conducted with an intention to include most of the major farming landscape types in the UK. The locations for the data collection were strategically selected across different regions, which helped to collect a representative sample across the UK. Although this scheme was targeted towards pre-dominantly arable farms, farmers with mixed farming types also chose to participate in the survey for this scheme. About 50% of the sample belonged to the southern parts of the UK (Cambridgeshire, Norfolk, surrey), which are pre-dominantly arable crop areas. Figure 6.1 shows the regional distribution of participating farmers across the UK.

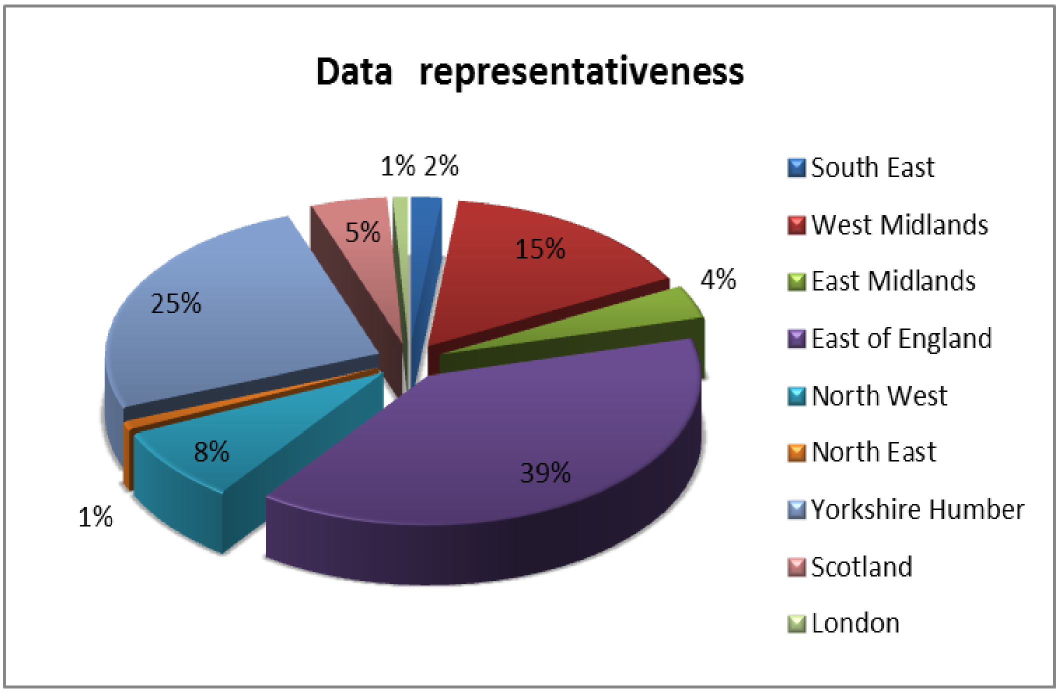


Figure 6.1 Regional distribution of the sample population

b. Age, gender, and household size:

The descriptive results (Table 6.2) revealed that 81% of the sample population were males. The majority of respondents were middle aged, with most of them (64%) being between the ages of 31-50 years, followed by 28% of respondents being in the older age range of 51-80 years.

About 41% of respondents had a household size of two, while 30% had three and 18% had a household size of 4. Only 8% of the respondents had more than four people living at home.

Table 6.2: Age, gender, and household size of the respondents

	Percentage (%)	Frequency
Age (years)		
17-30	8	9
31-40	27	31
41-50	37	42
51-60	19	22
61-70	8	10
71-80	1	1
Total	100	115
Gender		
Male	81	93
Female	19	22
Total	100	115
House hold size		
1	3	4
2	41	47
3	30	34
4	18	21
5	3	3
6	3	4
>6	2	2
Total	100	115

c. Level of Education:

The results (Table 6.3) show that 35% respondents went to college while 30% had been to secondary school. 20% had been to university for undergraduate and postgraduate degrees; however, 13% of the sample did not respond to this question.

Table 6.3: Education level of the respondents

Level of Education	Percentage (%)	Frequency
Missing	13	15
Primary school	2	3
Secondary school	30	34
College	35	40
Undergraduate	17	19
Postgraduate	3	4
Total	100	115

Table 6.4: Farm ownership, farm size, and income from the farm

	Percentage (%)	Frequency
Farm ownership		
Tenant	17	20
Own	83	95
Total	100	115
Farm size (ha)		
10-100	28	32
101-200	33	38
201-300	34	39
>301	5	6
Total	100	115
farm income (£/annum)		
£6,000-£30,000	10	12
£31,000-£60,000	28	32
£61,000-£90,000	30	35
>£91000	32	36
Total	100	115

d. Ownership of land, farm size, and farm income:

Table 6.4 displays that 83% of the farmers owned the farms they managed while the remaining 17% were either employed to manage the land or renting the land. The farm sizes varied considerably with most (67%) of the farmers being in the range of 100-300 ha. The farm income range was mostly at the higher end, and the dominant farm income (30%) range was £61,000-£90,000.

e. Land use and livestock types:

The pre-dominant land use was arable farming however; about 77% of the respondents also had certain percentage of grassland and livestock on their farms (Table 6.5). The arable crops varied into root crops, cereals, oilseed rape and farm vegetables. 50% of the sample operated pre-dominantly cereals farms. The statistics on livestock shows that about 55% of the farms had sheep along with dairy cows and cattle, while 45% had only cattle and dairy cows.

Table 6.5: Land use and livestock types of the farms

Livestock types and land use		
	Percentage (%)	**Frequency**
Sheep with dairy and cattle	55	63
Dairy and Cattle only	45	52
Total	100	115
Land use type		
Only Arable	33	38
Arable + Grassland	67	77
Total	100	115

6.5.3. Parameter Estimates of choice models

a. Estimates of CLM

The basic *conditional logit (CL) model* was specified so that the probability of selecting a particular alternative was a function of attributes and the alternative specific constant (ASC), which had a value of 1 if the 'do not want to participate' option was chosen and 0 if either of the other alternatives was chosen. This CL model provides a modest fit to the data (pseudo-R^2 of 0.20) and suggests that farmers overall show a reluctance towards participation in payment schemes which involve drastic changes in their current land use practices. The results (Table 6.6) show that most of the attributes have t-statistics significant at the 0.01% level. All the attributes except compensation (COMP) have negative coefficient values showing the farmers' reluctance to adopt the proposed changes, and preference to move away from the *status quo*. However, the positive and significant compensation attribute shows that farmers are more likely to participate when a scheme offers higher compensations other things being equal. The basic CL model did not identify significant preference towards any specific attributes and the IIA test also indicated that the basic CL model's assumptions of identical and independently distributed errors are not supported by the data; therefore, a more flexible model for preference heterogeneity was required. Socioeconomic interactions were added to the model, however, none of the characteristics revealed any significant coefficients.

b. Estimates of RPL

To account for this heterogeneity, *Random Parameter logit* (RPL) *model* was used. The sensitivity of RPL estimations to the number of draws used for simulations was tested and it revealed that the model based on 1000 draws provided sufficiently good approximations for estimations. Starting the RPL estimations, first, the utility parameters for all the attributes were specified as random choosing a *normal* distribution except for compensation which was specified with *log normal* distribution, in order to ensure non-negative parameters for this attribute. The results from this estimation revealed three attributes; permanent grassland (PGRASS), grazing time period (GRAZ) and ploughing method (PLOUGH), with significant standard deviations. Therefore, these were then specified as random parameters with normal distribution for the final estimations. The results (Table 6.6) show that the basic RPL model was statistically significant and R^2 value of 0.24. The log-likelihood ratio test rejects the null hypothesis that the CLM provides an equally good fit to the data at 5% significance level. The RPL results reveal that the standard deviation of the three random attributes, enrolling land for permanent grassland, grazing time period, and conservation ploughing are statistically significant showing these coefficients are heterogeneous over population. The results indicate that farmers are averse to most of the attributes and only show a positive preference towards conservation ploughing.

The results suggest that the data supports choice-specific unconditional unobserved heterogeneity. In order to further account for this heterogeneity in preferences and to explore the segmentation of respondents according to these preferences, the Latent Class model was estimated.

c. Estimates of LCM

The model was estimated over 2, 3, and 4 classes; however, the 4-class model did not converge. Both the 2 and 3 class model are statistically significant with 2-class model with a χ^2 statistic of 381.2. The log likelihood and R^2 values increased while the AIC and BIC values decrease from the 2-class to the 3-class model revealing that the 3-class model provided a better fit over the 2-class model. The results of the 3-class model are presented in Table 6.6 and they show that for segment-1 utility coefficients for PGRASS, REF and COMP are significant at 1% and 5% significance level, while for segment-2 all attributes except REF and LOA are significant. The segment-3 is the largest group with respondents having a 47% probability of belonging to this group. This segment shows significant preferences for most of the attributes at 0.01% level except the GRAZ. The farmers in segment-2 show higher resistance to participation as compared to the other two segments.

The results of the model estimations suggested considerable heterogeneity in preferences between the farmers. The LCM significantly divided the sample into three classes. Log-likelihood values indicate that the LCM provided an improvement in the overall fit as compared to the CL and RPL models. 47% of the population belong to the segment 3 of the LCM while the other two segments had almost equal populations each.

The results of individual characteristic class probability estimations did not show much significant distinction among the classes, the only variable that proved significant was *farm size* and revealed that farmers with larger farm sizes have a higher probability of belonging to segment-2 and show aversion to restrictions in land use activities, requiring higher compensation levels for uptake of the policy.

d. ASC (status quo) consideration

The model estimations for this policy scheme also revealed the same issue of ASC aversion as explained in the results section of Chapter 5. Therefore, a similar model without a constant was estimated for this scheme. The results (see appendix B) supported the issue found for mitigation policy in Chapter 5. Therefore, the ASC constant was ignored for welfare estimations for policy scheme alternatives carried out in Chapter 7.

Table 6.6: Parameter estimates from CL, RPL, and LCM models

Model	CLM	RPL (3 attributes random)		LCM		
Loglikelihood	-594.74	-617.95		-567.43		
Pseudo-R^2	0.2	0.18		0.25		
AIC	1.744	1.82		1.68		
BIC	1.794	1.904		1.78		
Chi squared		279.66		381.2		
Degrees of freedom		9		15		
				Segment 1	Segment 2	Segment 3
Attributes	Coefficient (SE)	Coefficient (SE)	St. dev(SE)	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)
PGARSS	-0.0657***	-0.0534***	0.032***	-0.2718**	-0.0746***	-0.054***
	(0.0050)	(0.0065)	(0.0068)	(0.0877)	(0.0119)	(0.0047)
REF	-0.0356**	0.1685		-0.1156*	-0.0034	-0.0423**
	(0.0120)	(0.1587)		(0.0494)	(0.0262)	(0.0136)
GRAZ	-0.3268*	-0.6832	0.7475**	0.01263	-0.5174*	-0.2016
	(0.1323)	(0.2145)	(0.2775)	(0.6192)	(0.252)	(0.1342)
PLOUGH	-1.1348***	0.0021**	1.6316***	-0.2007	-4.5855***	-0.4517***
	(0.1409)	(0.012)	(0.2416)	(0.484)	(0.4383)	(0.1363)
LOA	-0.0201*	0.0247*		-0.0446	-0.0146	-0.0313**
	(0.0096)	(0.0106)		(0.0365)	(0.022)	(0.0109)
COMP	0.0162***	0.3481***		0.0247*	0.0366***	0.014***
	(0.0027)	(0.0032)		(0.0107)	(0.0063)	(0.0028)
ASC	-2.5623*** (0.2570)			-4.9144*** (1.4600)	-3.0081*** (0.5671)	-3.1045*** (0.2821)
Percentage				26%	27%	47%

*, **, *** indicate statistic significant at 5%, 1%, and 0.01% respectively

6.6. Minimum WTA estimates for policy scheme

The overall marginal WTA estimates reveal that highest estimates are for segment-2 of the LCM at a value of £125.29 per ha for adopting conservation ploughing on their farms. Adopting conservation ploughing method has high values for most of the model estimations. This can be because this ploughing method can potentially be more labour intensive, as it also involves retaining an organic cover over the soil. The second highest values are for aversion to restrictions on grazing time periods.

Since, LCM proved to be the better fitting model; , utility estimates from the LCM were used to calculate individual-specific estimates and to calculate the individual-specific WTA values.

Higher ASC values, however, reveal that farmers prefer to move away from the status quo and are willing to participate in the proposed schemes. These results are contrasting to the observation that UK farmers are not presently converting to extensive practises, which suggests the presence of status quo bias in the data.

Table 6.7: WTA (in GBP/ha) estimations from the choice models for the sequestration payment scheme

Attributes	**CL**	**RPL**	**LCM 3 segment**		
			Segment 1	**Segment 2**	**Segment 3**
PGRASS	4.06	0.15	**11.00***	2.04	**3.86*****
REF	2.20	-0.48	4.68	0.09	**3.02****
GRAZ	20.17	1.96	-0.51	**14.14****	14.40
PLOUGH	70.05	-0.01	8.13	**125.29*****	**32.26***
LOA	1.24	-0.07	1.81	0.40	**2.24****

*, **, *** indicate statistic significant at 5%, 1%, and 0.01% respectively

Negative (-) minimum WTA values mean that the respondents do not require any compensation for adopting the suggested changes.

Kernel density plots were drawn help to represent the distribution of the population and their preferences according to their WTA requirements for each segment of the sample population. A description of the distribution for each attribute is presented below:

Enrolment for conversion to permanent grassland:

Figure 6.2 shows that all three segments have positive WTA requirements for this attribute. The first peak represents the respondents belonging to segment 2 and 3 showing the highest density point. The WTA values show that this attribute has been important across the population especially for the segment 2 and segment 3 respondents. The lowest peak in the density graph represents segment 1 respondents, revealing the least density in this compensation range while the highest population density belongs to the segment 3 of the LCM.

Enrolment for afforestation:

The respondents have lower WTA values for this attribute and farmers belonging to segment 1 and 3 have shown importance towards this attribute for their decisions. The density curves (Figure 6.3) are higher for segment 1 and segment 3. Though the sample does not require very high compensation amounts for enrolling certain percentage of their farmland for afforestation, farmers prefer to take up this conversion for lower arable land percentages.

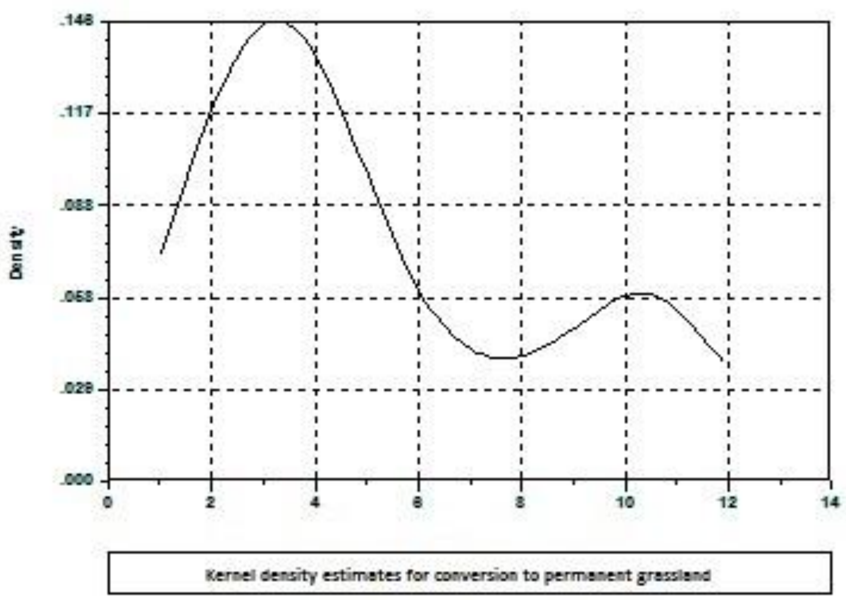


Figure 6.2 Distribution of individual-specific minimum WTA for enrolment of land for conversion to permanent grassland

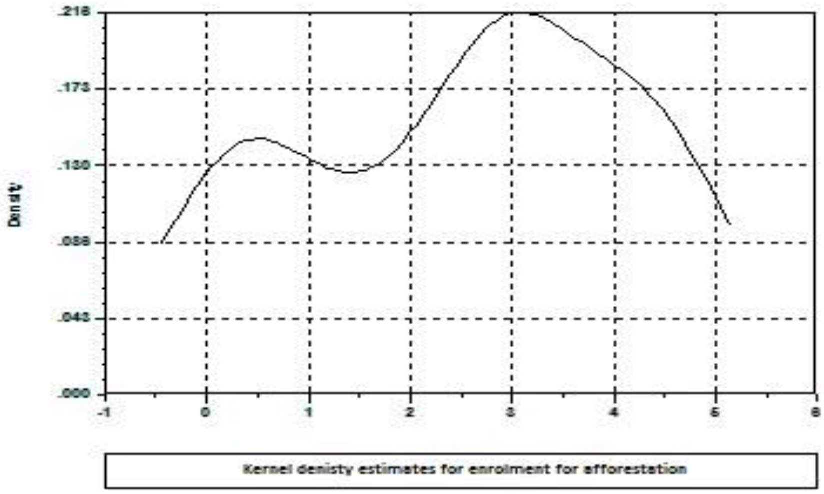


Figure 6.3 Distribution of individual-specific minimum WTA for enrolment of land for afforestation

Livestock grazing time:

This is the only attribute for which one class (segment 1) of the population does not require any compensation. The farmers in this segment include farmers with lower levels of livestock. The Figure 6.4 reveals that the highest population density lies within the compensation ranges of segment 2 and segment 3.

Ploughing methods:

The WTA values for this attribute though being in the positive range have been quite varied. The minimum being just £8.00 to the maximum value of £125 per ha required by the segment 2 respondents. This segment has shown a significant attitude towards this attribute. The model estimations revealed that farmers show preference for conventional methods of ploughing. This also explains the higher amounts of compensation required by most of the population.

Length of agreement:

The compensation estimations show that compensation values though being in the positive range were not very high. The minimum compensations are required by the segment 2 population and most of the population density lies within the segment 1 compensation range (Figure 6.6). This shows that though farmers prefer short term contracts, convincing them to participate in longer term contracts can be easily be achieved without offering high values of compensation.

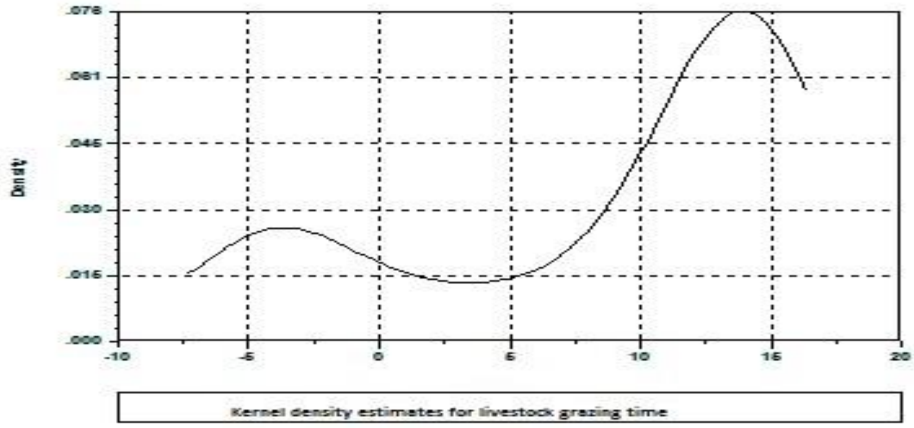


Figure 6.4 Distribution of individual-specific minimum WTA for changes in livestock grazing time

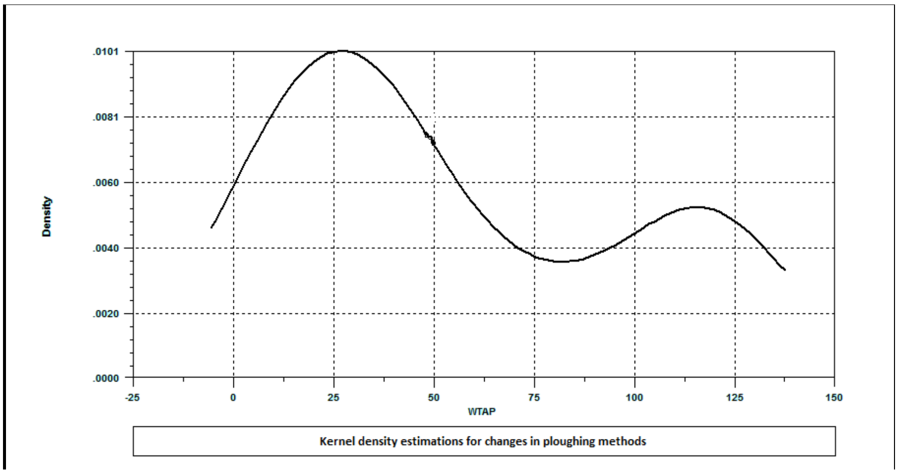


Figure 6.5 Distribution of individual-specific minimum WTA for changes in ploughing methods

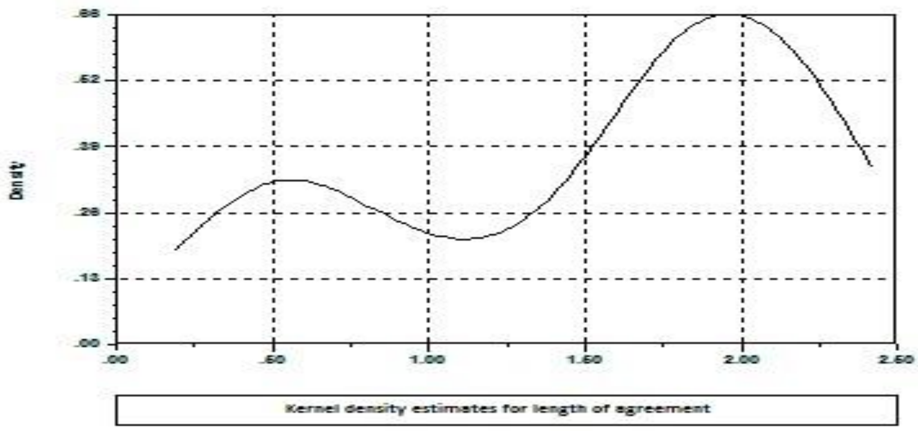


Figure 6.6 Distribution of individual-specific minimum WTA for length of agreement

6.7. Discussion

It is known from the literature that farmers prefer to enrol marginal land for conservation purposes and would prefer not to take land out of production. However, it is the land being managed intensively that is affecting climate regulation. Hence, it is important that conservation policies should be targeted towards arable land. The policy scheme was designed to address this by identifying target groups in arable areas in the UK.

A CLM, RPL, and LCM were used to analyse the data. It was revealed from the estimations that farmers show heterogeneous preferences for different land use management activities. The results suggested that farmers show aversion to drastic changes in their land use management activities but they can be encouraged to adopt some activities by providing the appropriate level of changes and compensation incentives and generally most farmers would prefer to participate in schemes with flexible and less restrictive measures.

The basic CL model estimations show that farmers' decisions are significantly influenced by all the scheme attributes and most of the farmers preferred no changes in the grazing time period and ploughing methods. The RPL model supported the assumption that the sample data shows unconditional unobserved heterogeneity, which was in accordance with most of studies looking into farmers' behaviour (Beharry-Borg *et al.*, 2012; Espinosa-Goded *et al.*, 2009; Ruto and Garrod, 2009). Three of the six attributes were estimated with a random term following a normal distribution with significant standard deviation. Though interacting socio-demographic data in the RPL can reveal this heterogeneity over the whole population (Hensher *et al.*, 2005), LCM was estimated to reveal the segmentation of the population, to identify the sources of preferences. This model revealed that the data could be categorised into three segments, however, segment-3 consisted of almost half the population (47%).

The results revealed a preference towards short term contracts for this scheme as well but the models failed to provide clear source of heterogeneity in terms of socio-economic characteristics. Hence, unlike the mitigation scheme (presented in chapter 5), no specific target groups could be identified. However, achieving carbon sequestration targets require longer time period, hence, there is a need to design schemes which provide farmers with low cost measures which can be sustained over a longer time period even in the absence of the scheme.

The sample profile discussed in subsection 6.5.2 shows that most of the sample consists mostly of mixed farms with only 5% sample managing arable land only. The sample consisted of mature farmers with an average age of 45 years, most of the sample (83%) managing own farms. The average farm size of the sample (166ha) was much higher than the UK average of 77ha (DEFRA, 2012). The CE results for this sample group did not provide clear information on the influence of the farm/farmer characteristics on the decisions made by the respondents. This could potentially be due to the mixed nature of the farms and unrepresentative distribution of the socio-demographics across the sample. This reveals a need to stratify the sample population into clear profiles to further investigate the implications of the nature of the farms and farmer characteristics on the uptake of sequestration schemes in arable land.

The WTA estimates show a strong aversion to extensive grazing and adopting conservation ploughing. The results revealed that the farmers require significantly higher compensation values for these two attributes. The individual specific estimations showed that segment 2 proved to be the most averse segment of the sample, as they require highest amount of compensation for most of the changes required by the scheme, except enrolment of land for conversion to permanent grassland. In accordance with the literature, a considerable number of farmers were willing to adopt the proposed changes if sufficient payments were offered (Beharry-Borg *et al.*, 2012; Christensen *et al.*, 2011; Ruto and Garrod, 2009).

Methodologically the study shows that CL and RPL models can provide useful information on the main drivers of heterogeneity, however, CL-int was not able to specify any significant results. LCM is usually required to show a more distinct distribution of that heterogeneity, however, the models were not able to clearly identify preference drivers for this scenario. This is in accordance with Beharry-Borg *et al.* (2012) and is potentially attributed to the mixed nature of the supposedly predominantly arable farms and a relatively small sample size.

These findings can be relevant and important for informing any PES scheme design. The estimations suggest that the possibility of attracting farmers to enhancing carbon sequestration exists but higher compensation payments are required. By considering the heterogeneity of farmers, it has been shown that there is a potential for attracting farmers at the lower WTA spectrum by keeping some flexibility in the level of action required for the measures included in the scheme designs.

6.8. Conclusions

This chapter focused on a CE study to explore farmers' behaviour towards changes in land management practices required for enhancing carbon storage in arable farms. A policy scheme was designed to identify the target groups in arable farmlands of the UK.

The CE estimates show that farmers can be grouped according to the utility and disutility they get from the same attributes. The results revealed that this difference of behaviour can be attributed to the scheme design (attributes), however, it was unable to illustrate the influence of farm/farmers' characteristics on the preferences. From the attributes presented in this study, it was revealed that a significant proportion of respondents do not require high compensation for enrolling a lower percentage of arable land for conversion to permanent grassland and afforestation. However, making them adopt conservation ploughing or extensive grazing can prove very costly in terms of compensation. This shows that the respondents revealed disutility towards restrictions in grazing and conservation ploughing methods. The survey also revealed that most of the farmers were under the impression that these measures can be more troublesome and would cause a reduction in overall productivity of their farm. Policy makers should be able to address this disutility in such scheme designs. This can be achieved by providing help or assistance in adopting such restrictive farming activities and by enhancing awareness of the benefits of these measures.

This study also contributes to the literature on the estimation of the economic cost of provision of carbon sequestration service from UK farmlands. Since it is a non-marketable service, the farmers have no means of revenue generation from it. Therefore, payment schemes can be helpful to provide compensation for undertaking the required changes. Based on these results from the choice experiment it can be concluded that farmers show aversion to changing land management, and prefer to participate in schemes requiring lower levels of action. This leads to the conclusion that implementation of such schemes will require proper planning, design, and appropriate compensation amounts to ensure uptake by UK farming community.

The insights gained through this study can be used to address the climate regulation services provided by UK farmlands. It also provides a basis for a further plausible cost-effectiveness study to address the potential costs of achieving carbon sequestration through land use management activities.

In summary, this chapter provides an insight into farmers' behavioural preferences towards land use management options that can help to enhance carbon sequestration in UK arable farms. This study contributes to the PES literature for carbon sequestration by using a holistic approach rather than focusing on a single measure i.e. it contains measures which involve the whole farm as a unit, such as, arable land conversion to grassland and afforestation, and suggesting changes in livestock grazing and ploughing methods. The study was able to associate farmers' preferences to the scheme design however, the impact of socio-economic characteristics is still vague and the study failed to provide a very clear interpretation of the segmentation of farmer groups. This can be attributed to the mixed nature of farms and smaller sample size (as compared to the sample size for the mitigation policy scheme presented in Chapter 5). The issue related to the nature of farms can be potentially addressed by linking the land uses with landscape and farm characteristics, which can lead to a more pronounced identification of the target farms and can help to design schemes accordingly. Nevertheless, the key findings provide a base for incorporating this kind of analysis for designing potential schemes. Furthermore, cost-effectiveness analysis of such schemes can help to address the specific costs of carbon sequestration in terms of carbon cost of each farm. This can help to implement the schemes in a cost effective way to encourage farmers to adopt changes to achieve the required climate change mitigation targets. This cost-effectiveness analysis will be presented in the following chapter.

Chapter 7 Spatial pattern of Carbon Valuations

Abstract

Voluntary Environmental policies can be used to provide incentives e.g. ES conservation and protection. Effective design of these policies can benefit from information on the heterogeneity of preferences of farmers towards scheme attributes. In agroecosystem context the variability in environmental and farm characteristics, which often vary over space, can also, play an important role for how costly it would be to use different types of policies to achieve reductions in net carbon emissions. This chapter estimates carbon abatement costs from the CE studies. These are combined with GIS based techniques to allow for an assessment of cost-effectiveness of two policy schemes and an investigation into the spatial distribution of these costs. The WTA estimates from the CE studies reported in Chapters 5 and 6 were used for the carbon abatement cost calculations while the land use model outputs for the baseline scenario presented in Chapter 4 were used for the spatial analysis. The results show that a scheme using agro-ecosystem to sequester carbon is more efficient than the scheme designed to a technology based scheme to reduce emissions. The carbon valuation also revealed that almost half of the sample was within the DECC price range revealing that appropriate policy implementation can be achieved at reasonable cost. The spatial mapping revealed target locations where implementing such policies can be more cost-effective. These results have implications for policy design and appraisal for achieving emissions reduction targets in the UK farmlands.

7.1. Introduction

Ecosystem services (ES) from agroecosystems which strongly contribute to human wellbeing, are being affected negatively by the increased population, agricultural intensification, and climate change. Hence, conservation of the ES from this sector needs to be included in the social, economic, and institutional systems (Broch *et al.*, 2013). Although understanding the drivers contributing towards enhancing the conservation of ES can be useful to guide effective policy support, an evaluation of the costs associated with these policies is also important. This puts emphasis on the need to implement PES schemes to achieve desired benefits at least cost (Chen *et al.*, 2010). This way the programmes can be made cost-effective by enrolling lands which provide maximum benefit within an affordable budget.

There is a need for a robust approach to develop such cost budgets to ensure the effectiveness of policies. In the literature two major approaches have been used for carbon pricing, the social cost of carbon (SCC) and marginal abatement costs of carbon (MACC). The SCC is the marginal damage cost of emissions and is estimated for every additional tonne of carbon emitted to the atmosphere (Watkiss and Downing, 2008) while the MACC is the cost of mitigation of one tonne of carbon based on a mitigation measure or technology (Moran *et al.*, 2008).

Spatial mapping of ES and their monetary values have been quite popular and is gaining much attention e.g. UKNEA, 2011; Natural Capital Project (Termansen *et al.*, 2013). Mapping of ES values is defined as *valuation of ES across a relatively large geographical area that includes exploring variation of these values across space* (Schägner *et al.*, 2013). Mapping welfare estimates can help to provide additional information for designing efficient policies as it provides information regarding the differences in values across space and their spatial determinants. There is a need to develop spatially explicit models combined with value functions based on real world observations. This leads to an investigation of the variations in the welfare estimates and spatial heterogeneity for carbon valuation studies to achieve climate regulation conservation in the agricultural sector. This can help to generate spatial patterns of economic values highlighting cost effective locations for the implementation of individual policies. Chapters 5 and 6 provided an account of heterogeneity in farmers' preferences and the farm/farmer characteristics that affect their preferences. However, agricultural land is privately owned and is quite heterogeneous according to spatial location and landscape characteristics, therefore, understanding the linkage between farmers' preferences, spatial characteristics and distribution of ES can help identify areas which can be targeted effectively with policies.

This chapter examines these two aspects of effective policy design. First, it estimates the costs that each respondent associates per tonne of carbon emissions avoided from the enrolled land. Although MACC have been calculated by various studies for individual measures (see Moran *et al.*, 2008), research for carbon costs for complete policy programme has been limited mostly to programmes for carbon sequestration by forestry and afforestation (see Richards and Stokes, 2004). This study attempts a more holistic approach to provide carbon abatement costs for whole policy alternatives for both carbon sequestration and GHG mitigation by changes in agricultural land use activities and management. The CE study in the preceding chapters provided the WTA estimates for farmers to contribute towards enhancing climate regulation. These monetary estimates can be used to calculate the carbon abatement cost per tonne of CO_2 equivalents for each individual farm. Furthermore, it investigates interdependence between carbon costs and the farm and landscape characteristics. Since it was revealed from the CE study that, farmers' preferences are heterogeneous and are dependent on various factors such as scheme design, farm, and farmer characteristics;

The effect of the spatial distribution of these characteristics and preferences are investigated. This will be done by linking the carbon values with the spatial patterns of the individual farm.

The chapter begins with a review of background literature in Section 7.2 which leads to the specific objectives for this study, followed by a description of the data and framework of the study (section 7.3). The estimations along with a discussion of the results are presented in section 7.4. The chapter ends by wrapping up the conclusions of the analyses carried out (section 7.4).

7.2. Conceptual approaches in spatially-explicit carbon valuation

7.2.1. Carbon valuation

Carbon valuation is important for effective policy design and implementation for dealing with the issue of climate change. Estimations of carbon values have included integrated assessments combining physical climate models with an economic growth model to determine the benefits of climate policy and comparing marginal benefits with marginal costs. Three approaches have been employed to estimate the value of carbon; market price – reflects the values of traded carbon emission rights to those in the market through policies (e.g. EU ETS), Social cost of carbon (SCC) – based on the current global cost of an incremental unit of carbon emitted, Marginal abatement cost of carbon (MACC) – based on the cost of reducing emissions (Price *et al.*, 2007).

The market price takes into account the existing price of a tonne of carbon traded in accordance with a certain policy. This price is used by the business community and it relates to a pre-set target. The SCC is based on the lifetime damage costs associated with GHG emissions (DECC, 2009). The SCC estimates the full effect on social welfare of reducing the emission of carbon by an additional unit over the lifetime of that unit of carbon in the atmosphere. It provides a theoretical optimal solution in terms of the price that society should be willing to pay now to avoid the future costs resulting from increasing carbon emissions. However, this optimisation approach has been criticised due to the contested basis for monetary valuation of the uncertain climate impacts including the choice of discount rates for future climate change impacts (Downing *et al.*, 2005; Ekins, 2007).

On the other hand, DECC (2009) suggested that carbon valuation should be based on estimates of abatement costs of specific emissions. MACC is one such approach as it is based on the marginal cost of reducing carbon emissions by one tonne (for details refer to Moran *et al.*, 2008). MACC represents the UK government's preferred approach to carbon pricing and is the source of official non-market carbon price (DECC, 2009). It has been suggested that MACC has an advantage over the SCC approach as the costs are based on existing activities and technologies, and can therefore be relatively easily estimated empirically (Dietz, 2007). The carbon valuation estimates are helpful in guiding decisions on the targets for emission reductions and setting up carbon taxes and charges for the damage caused by the emissions.

For evaluation of hypothetical policies or programmes for provision of ES (for this study climate regulation service), a target-consistent approach, by estimating the expected carbon captured or abated and the cost of abatement or storage can be more useful (DECC, 2009). This helps to take into account all relevant costs and benefits to assess if a particular policy can improve or reduce the provision of the service.

Hence, for this study MACC was considered to be the preferred approach. MACC is a bottom-up analysis representing the costs and abatement potentials for mitigation measures, and it is also useful in providing illustrative comparison of various measures according to their cost-effectiveness. The current study calculates the carbon abatement costs using the compensation the farming community is willing to accept for the provision of regulatory services by agroecosystems.

7.2.2. Spatial distribution

Spatial analyses can help to evaluate land use policies by displaying trade-offs in values of multiple services resulting from land use change. It can also help to design effective payment scheme policies by providing spatial variation of values and identifying the areas of maximum conservation potential. This provides an understanding of the spatial determinants of the ES delivery and the associated value to society (van Berkel and Verburg).

While investigating heterogeneity in participation behaviour is useful for effective policy design, spatial distribution and its effect on the willingness to participate also needs to be taken into consideration. Preferences for various ecosystems and ES such as water quality improvement, agricultural land use management, recreation etc. can be linked to spatial distribution and characteristics. Studies have employed spatial analyses to improve accuracy in travel cost studies (Bateman *et al.*, 1996), explore distance-decay relationships in environmental values (Bateman *et al.*, 2006), explore spatial patterns in willingness to pay for rural landscapes for estimates from CE (Campbell *et al.*, 2009), estimate spatial patterns of willingness to supply ES in agricultural landscapes (Broch *et al.*, 2013), assessed the preference heterogeneity related to spatial distribution of water improvements throughout a river basin (Brouwer *et al.*, 2010), investigate spatial heterogeneity in forest recreation (Termansen *et al.*, 2013), and explore potential impacts of carbon pricing on possible land use changes (Abson *et al.*, 2013).

For policies focusing on climate abatement in agricultural sector there is a need to identify cost-effective measures. Hence, the carbon valuation presented in this chapter focuses not only on the costs farmers associate with the increase in the provision of climate regulation service provided by UK agroecosystems in order to identify potential drivers for demand of carbon abatement and participation in voluntary schemes but also explores the spatial variation of the carbon values. The specific objectives of this study are;

1) To estimate the carbon abatement costs for potential policy schemes and compare the cost-effectiveness of the schemes.

2) To provide an analysis of the spatial pattern of the carbon costs through PES schemes across the UK to identify the areas of highest potential for effective implementation of these policies.

7.3. Methods and data

7.3.1. Study framework

The analysis involves estimation of carbon abatement costs for the two levels of action (low and high level) for the mitigation and sequestration policy scheme, comparison of the effectiveness the carbon costs for individual farms with the DECC (2009) carbon prices, and exploration of the spatial distribution of these values.

As mentioned earlier, a MACC approach was adopted for the carbon abatement cost estimations. The first step was to calculate carbon emissions according to emissions abated in line with the adoption of policy scenarios. Second, was to estimate the carbon costs for these emissions for individual farms using the farmers' willingness to accept compensation for signing up to the scheme.

Statistical analysis was conducted to further explore the heterogeneity in the distribution of these values according to land use characteristics and carbon emissions from the baseline year and individual farmers' characteristics. The individual farm analysis was complemented with a landscape scale analysis. This was done by combining the abatement potentials and costs with the land use model output from the business-as-usual (BAU) year (2004) presented in Chapter 4 to explore the trend in carbon abatement costs across the grids.

7.3.2. Data

Multiple data sources were used for this analysis. The data and outputs from the first two stages of the research was combined to conduct a carbon valuation study for the policy schemes evaluated in the previous chapters, and is presented in detail in the following subsections.

7.3.2.1. Carbon Valuation

The carbon costs were calculated as carbon abatement costs from the WTA estimates for incentivising farmers to participate in carbon management schemes (Chapter 5 and 6). These were estimated by calculating annual changes in potential equilibrium carbon stocks and the changes in annual emission (flows) of GHGs resulting from participation in two potential schemes i.e. mitigation and sequestration policy schemes. This analysis was based on the framework developed in Chapter 4. These annual GHG changes were then combined with estimations of costs of participation from the CE study. The GHGs included in the analysis are carbon dioxide (CO_2 - from land use change) and methane (CH_4 - from livestock manure) which were converted to CO_2 equivalents (CO_2e). The steps involved in carbon abatement calculations are presented below:

a. Defining the schemes

First the two schemes were defined in terms of the measures and levels of intensity of measures or changes. The mitigation policy scheme was designed to mitigate GHG emissions from livestock manure by setting up anaerobic digestion (AD) plants while the sequestration policy was designed for changes in land use management activities. These land use change measures included conversion from arable to grassland, arable for afforestation, restrictive grazing, and conservation ploughing. The two alternative categories for each scheme are presented below:

- **MIT-1 (OFAD)**: On-farm digestion plant with technical assistance retaining ownership of the plant for a 5 years contract.
- **MIT-2 (CAD)**: Centralised digestion plant to be shared with neighbouring farms without technical assistance, maintained by a power supply company for a 10 years contract.
- **SEQ-1 (Low action)**: Enrolling 10% of arable land for conversion to grassland, 2% for afforestation, with intensive grazing and conventional tillage on the remaining arable land for a 5 years contract.
- **SEQ-2 (High action)**: Enrolling 30% of arable land for conversion to grassland, 10% for afforestation, with extensive grazing and conservation tillage on the remaining arable land for a 10 years contract.

b. Data for emissions abated

The potential carbon emissions for the mitigation scheme were calculated by combining the number of livestock with emissions factors for each animal (Table 7.1). The data for per head estimates of GHG from livestock manure were based on UK species specific emission factors from Jackson *et al.* (2009) also used for the estimations in Chapter 4. This provided the potential emissions that can abated for that particular farm.

The data (Table 7.2) for carbon sequestration due to the changes in land uses was taken from Warner *et al.* (2008). The soil carbon (SOC) and above ground carbon (AGC) calculations were done for every additional measure required by the policy scheme. Therefore, the carbon sequestered for restrictive grazing was calculated by calculating the difference of carbon stored while moving from intensive to restrictive grazing and were then combined with the restrictive grazing estimates for the additional area of land converted to grassland. Similarly, for potential carbon storage for conservation tillage was calculated for only the land left after enrolment for the required changes.

The GHG emissions and carbon sequestration estimates were combined with individual compensation estimated to calculate the cost of abating a tonne of carbon (1tCO_2e) for each farm for the two policy alternatives.

Table 7.1 Data for calculation of emissions per head of livestock

Livestock	Excretion per animal (KgN/animal/yr)	Emissions (tCO_2e/ha/yr)
Dairy	111	0.41
Cattle	48	0.17
Pigs	11	0.04

(Source: Jackson *et al.*, 2009)

Table 7.2 Data for calculation of emissions from land use change and farm activities

Land use activity	Land use conversion				Land use activities		
	Arable to grassland		Arable for afforestation		AGC[a] storage for Intensive grazing	AGC for Extensive grazing	SOC[b] for Conservation till
	SOC	AGC	SOC	AGC			
Emissions (tCO_2e/ha/yr)	3.32	0.73	3	2.2	5.9	8.8	0.7

AGC is above ground carbon (carbon stored in vegetative parts), SOC is soil organic carbon

(Source: Warner *et al.,* 2008)

The potential GHG abatement was calculated for emissions from livestock and carbon sequestered for each land use change and activity for individual farms. These calculations were then combined with the welfare estimations to explicitly provide costs of carbon abatement for each participating farm. The costs were based on the welfare estimations from the CE study presented in Chapters 5 and 6. These estimates were considered as the costs of taking up the policy schemes.

c. Welfare estimates from CE study

Welfare estimations provide information regarding the monetary impact of the change. As discussed in Chapter 3 welfare estimations are calculated for the situations before and after the change, hence, subtracting the marginal utility of status quo from the marginal utility of all programme attributes. However, as seen from the CE results including the status quo constant revealed that although it improved the model fit, it still revealed some bias in the estimations and failed to explain the choice in terms of observable attributes. Other studies in the literature have also argued for not including the ASC in welfare estimations (see Adamowicz *et al.*, 1998; Boxall *et al.*, 1996; Hess and Beharry-Borg, 2012). Therefore, it was decided to exclude the ASC from the estimations of farmer payment requirement to sign up for the two policy scheme scenarios presented in Chapters 5 and 6.

From the model statistics (presented in Chapters 5 and 6) it was revealed that LCM provides an improvement to both CLM and RPL, hence, LCM was preferred for the calculations of the individual welfare estimates and the carbon costs analysis for the schemes.

d. Carbon costs calculations

The individual hectare payments multiplied by the total farm size[13] is the marginal cost of enrolling an additional farm into the scheme. Using the marginal abatement cost approach the carbon costs for each participating farm were calculated as:

$$CCost = \frac{MCost}{CAbate}$$

Where, CCost is the annual cost of carbon (pounds per tonne of carbon equivalents), MCost is the marginal cost of measure (WTA estimates for individual farm) and CAbate is the potential carbon abated (tonnes) if the policy scenario is applied to that farm.

The marginal abatement cost curve was generated by arranging the marginal cost estimates according to increasing carbon costs. The marginal cost curves were derived by plotting these cost estimates against the cumulative carbon abatement quantities for the policy scenarios and levels across the sample farms (Figure 7.1). Thus, the marginal costs expressed the cost of abatement of additional ‘n’ tonnes of carbon equivalents.

7.3.2.2. Regression analysis

Only illustrating the spatial distribution of carbon valuation would not provide enough information about the sources and causes of differences in trends. Therefore, regression analysis of carbon abatement costs against landscape and farm/farmer characteristics was conducted. The data for the landscape characteristics was taken from the BAU year used for the estimation of changes in

[13] The compensation payments offered to the respondents were as per hectare payments for the total farm size.

regulatory services (Chapter 4) and included agricultural land use, livestock units and carbon emissions. This analysis was carried out to further explore and understand the variations in carbon costs.

7.3.2.3. Spatial heterogeneity

To explore the spatial heterogeneity in the carbon abatement costs calculated for the designed policy scenarios, it was necessary to link the valuation data with the spatial data. This was done by translating the preferences for policy adoption into maps allocating each individual respondent the specific location of the farm using ArcGIS (ESRI® ArcMap™ 10.0). Only the respondents with valid and identifiable postcodes could be included in the spatial analysis. Therefore, 355 respondents out of the total 380 sample collected through the CE survey were mapped across the UK.

The calculated carbon values for each individual were also added to each point (respondent) on the map. This layer was then combined with the BAU (2004) data layer from the estimations in chapter 4. This layer contained land use and emissions data for the UK; hence, overlaying and cross tabulating the two layers provided a layer with complete data for the CE survey respondents.

Each respondent was assigned a complete grid according to its location. It was assumed that each respondent's preferences could be applied to represent the whole grid. Potential carbon emissions were calculated for each grid in accordance with the requirements of the preferred policy scheme. This provided an estimate of emissions that can be abated across each grid by implementing a particular scheme at a certain cost. The detailed spatial analysis was undertaken at landscape level to include each land use and livestock type. This helped to examine possible trends in the differences and variation in carbon valuation according to the location, land use and livestock type.

7.4. Results and discussion

This section provides an account of the results and discussion of the estimations done for the carbon valuation and spatial distribution.

7.4.1. Data representation

To illustrate the representativeness of the sample across the UK, the area of the sample was calculated by combining the sample size (that could be plotted for the spatial mapping) with the area of each grid. The total sample area was calculated to be 142,000ha of the total UK area. The distribution of respondents according to their preferences towards the alternative policy schemes is presented in Figure 7.1.

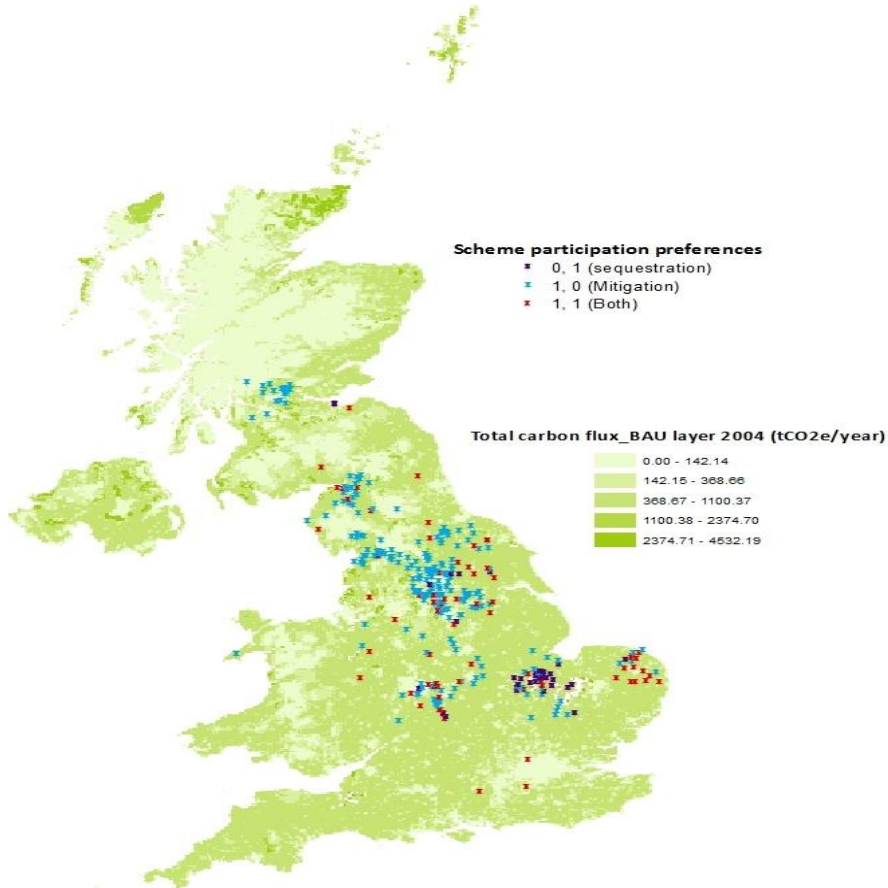


Figure 7.1 Map showing the preference of respondents towards policy schemes

7.4.2. Carbon Valuation

The estimations revealed that sequestration policy has a lower cost of carbon and it has a potential to mitigate higher amount of carbon as compared to the mitigation policy. Figure 7.2 shows a very steep ascending curve for the adoption of AD plants though the emissions abated across farms remains relatively constant.

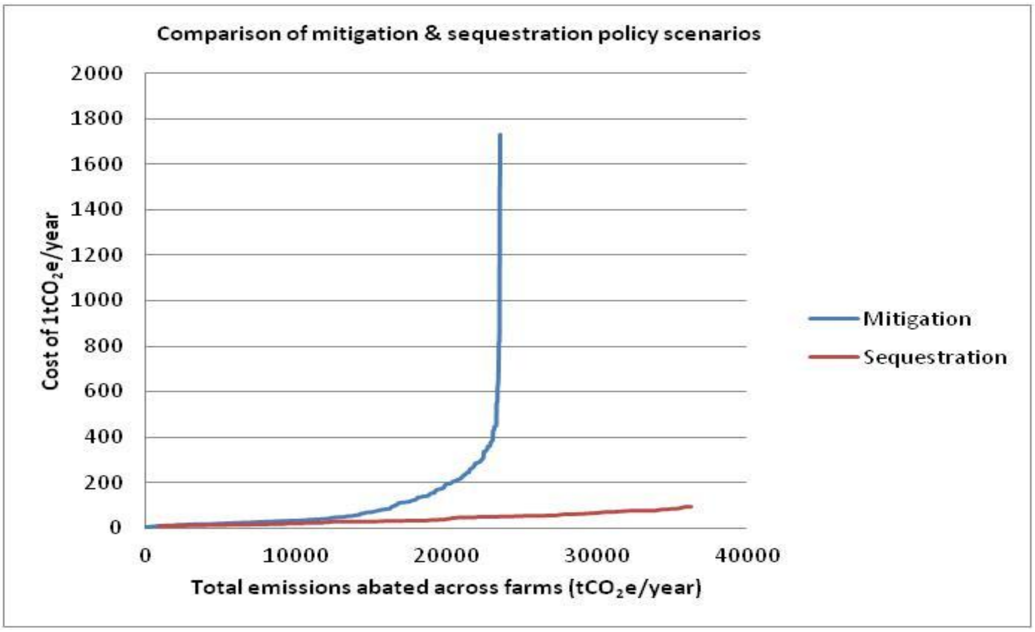
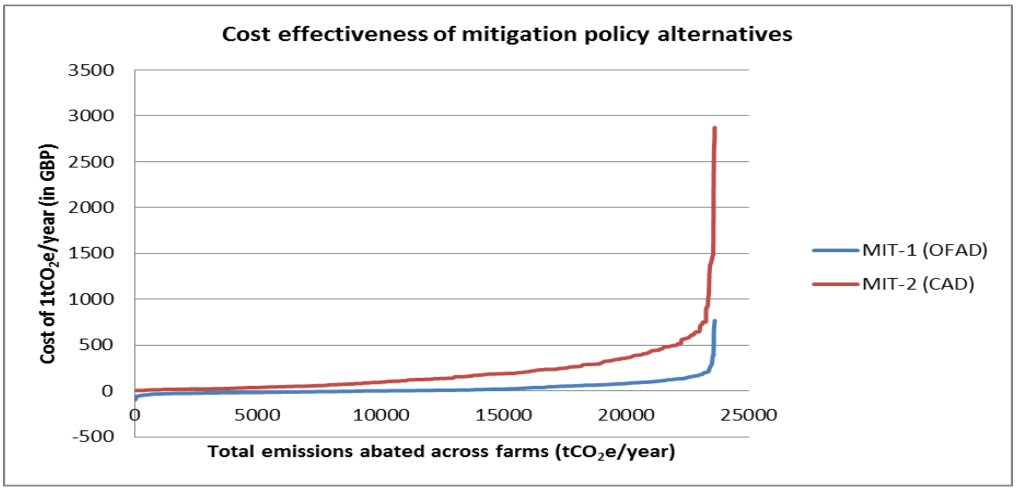


Figure 7.2 Comparison of cost effectiveness of mitigation and sequestration policy scenarios

Further investigations of the farmers' decisions within each policy scheme were conducted by considering two alternatives based on the level of action for each scheme (Figure 7.3 a & b) and revealed large variations in per hectare compensation required for the two policy schemes. These results further supported the findings discussed above as the cost curves for the mitigation policy revealed that MIT-1 (OFAD) is a cheaper option to attract farmers for mitigating manure emissions from livestock as compared to centralised AD plants.

A similar pattern was reported for the estimations for sequestration policy, revealing that low action alternative (SEQ-1) will prove cheaper to implement.



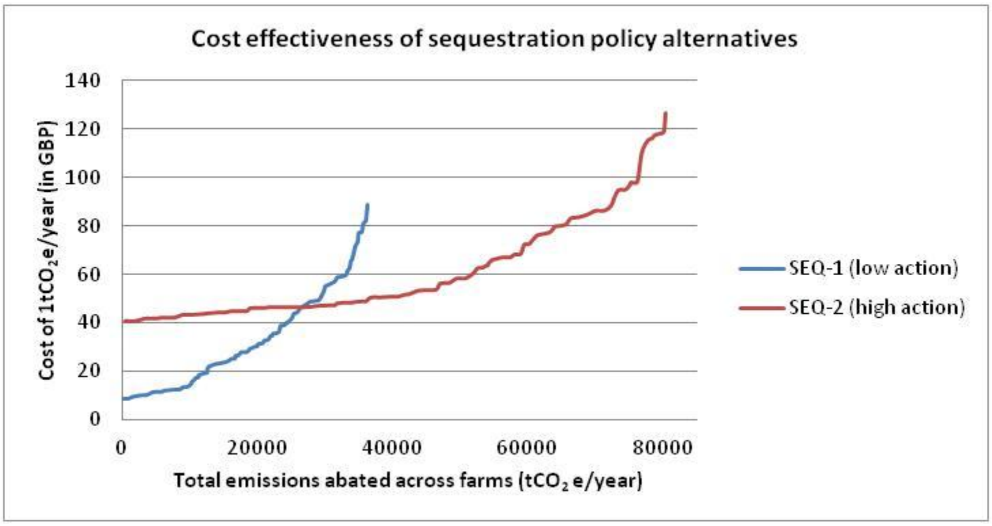


Figure 7.3a & b Carbon abatement costs of mitigation and sequestration policy alternatives

Considering the annual costs estimations of both policy schemes the mean yearly costs of 1 tonne of carbon were £130 and £40 for mitigation and sequestration schemes respectively. Comparing the abatement curves with the DECC and Stern carbon pricing (Table 7.3) show that the costs for the sequestration policy are more consistent with these costs as compared to the very high values for the mitigation policy scenario. Further comparison of the carbon costs with the DECC (2009) pricing also revealed that approximately half of the sample was within the DECC price range for overall cost of 1tCO_2e/year.

Table 7.3 Carbon pricing (2010 prices)

Year	Stern 550ppm emissions trajectory (£/tCO_2e)	Stern BAU emissions trajectory (£/tCO_2e)	DECC 2009 (£/tCO_2e)
2004	£25.47	£88.38	£44.69
2020	£34.96	£121.32	£58.29
2040	£51.95	£180.28	£131.15
2060	£77.20	£267.89	£258.41

7.4.3. Regression analysis

The regressions analysis was conducted for various farm, farmer and for the BAU scenario characteristics by assuming that the preference of each respondent represents the BAU grid as a whole (only significant variables are shown in Table 7.4). The regression estimates are highly significant and R^2 is 0.24. The analysis revealed that farms with higher livestock units and larger arable land have lower carbon costs, suggesting that larger farms have a more positive preference towards participation in the schemes. This relationship is also shown at the landscape level as landscapes with a high share of arable land in the BAU scenario also tend to have lower costs of scheme participation.

Table 7.4 Regression analysis of carbon costs against land use variables

Variables	Coefficients	Standards errors
Farm/farmer characteristics		
Constant	121.83	21.2509***
Farm size	1.1149	0.1307***
Arable land	-1.05622	0.1659***
Livestock units	-0.60181	0.0767***
BAU Landscape characteristics		
Constant	171.865	32.8415***
BAU year arable land	-0.4488	0.1618**

*, *** indicates statistical significance at 5%, 0.01% respectively

7.4.4. Spatial distribution of carbon values

The carbon costs for the two policy schemes were estimated according to the agricultural land and livestock numbers of each grid. The emissions for each grid were estimated for the number of livestock and the agricultural land. The welfare estimates of each respondent were combined with these emissions to calculate cost of each tonne of carbon abated annually (tCO_2e/yr). Figure 7.5 illustrates the spatial distribution of carbon costs across grids.

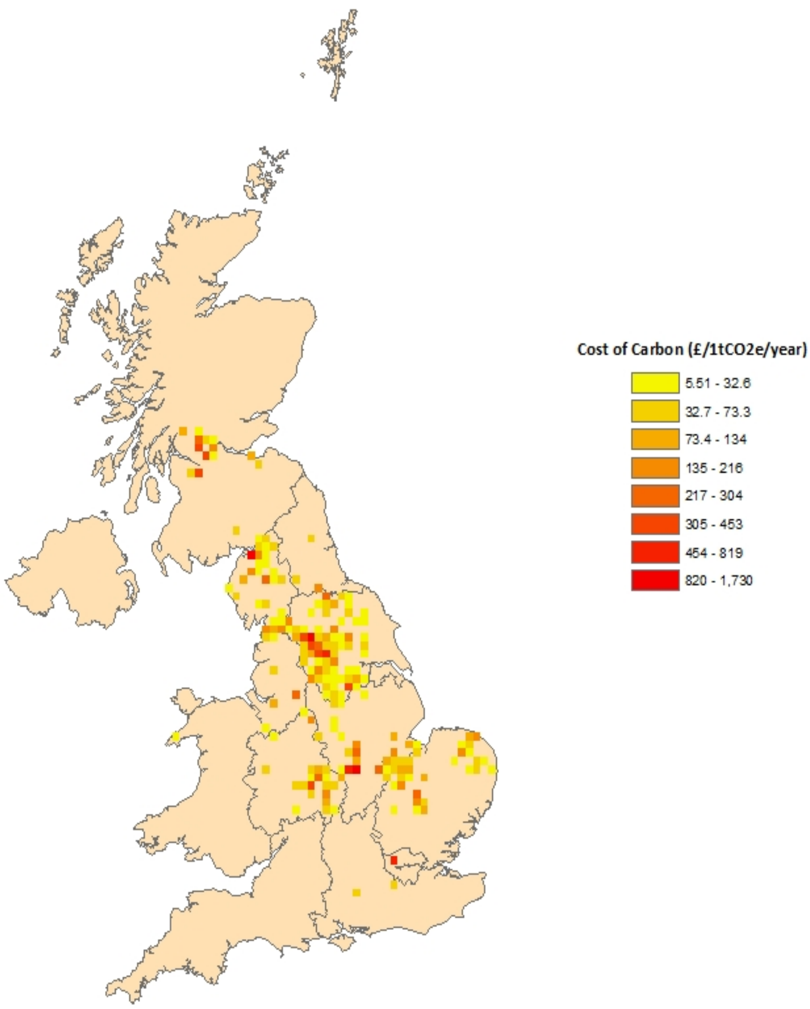


Figure 7.4 Distribution of carbon values across grids

The regional variation in the costs of carbon reveals that Scotland, North of England, and Midlands have higher rates as compared to the southern parts of the UK. This can potentially be because these farming landscapes include hill farms with cattle and sheep and dairy farms while the southern parts include more arable landscapes.

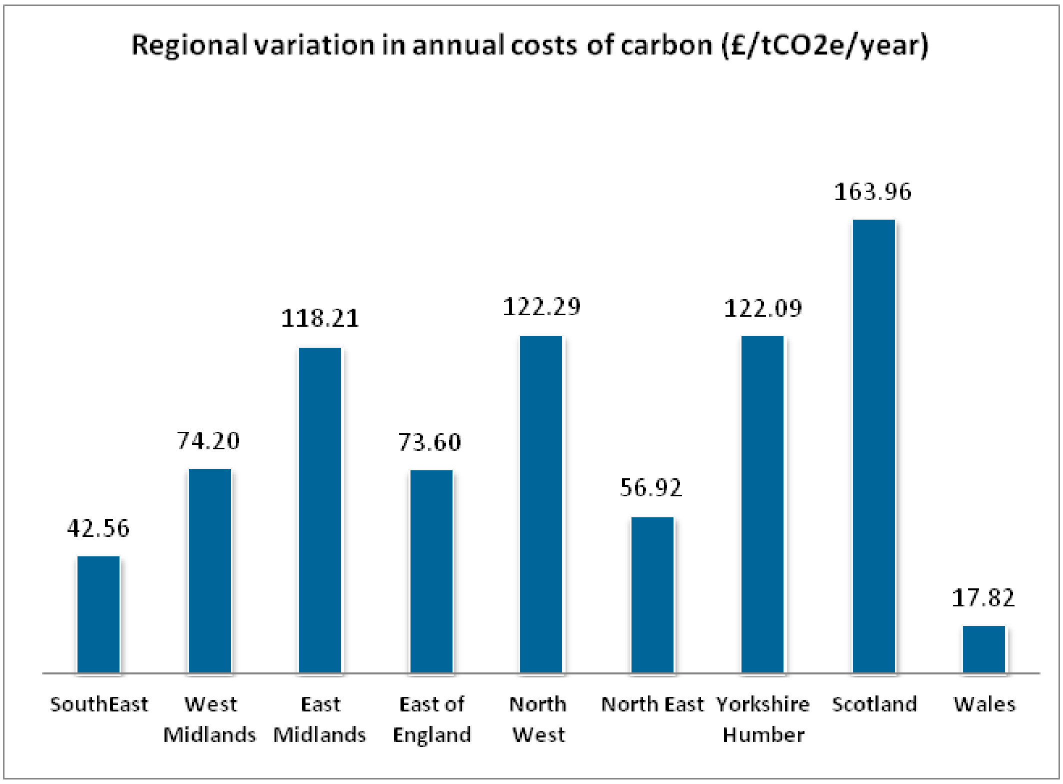


Figure 7.5. Regional variations in carbon values

The spatial mapping of the carbon values was employed to illustrate the spatial distribution of these valuations. This helped to identify the areas which offered highest mitigation potential where it would be cheaper to implement the policy in terms of carbon costs. This was done by calculating the change in emissions across grids of the BAU (2004) year. These emissions were calculated according to the land use and management changes proposed by each policy scheme. The costs were plotted against the accumulated emissions savings across the grids to illustrate the comparison of the cost curves for the two policy scenarios (Figure 7.6). The graph shows a low steady curve for the sequestration policy scenario, showing a potential for higher carbon abatement at low costs for additional tonne of carbon abated across the grids. However, the mitigation policy reveals a high and steep cost curve.

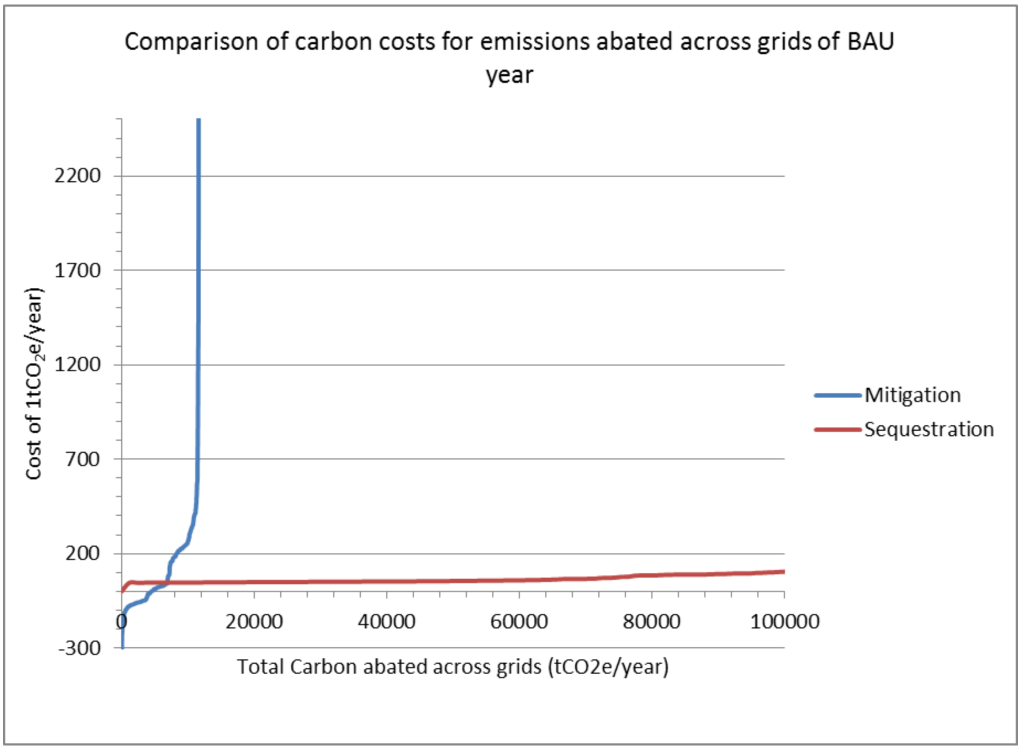
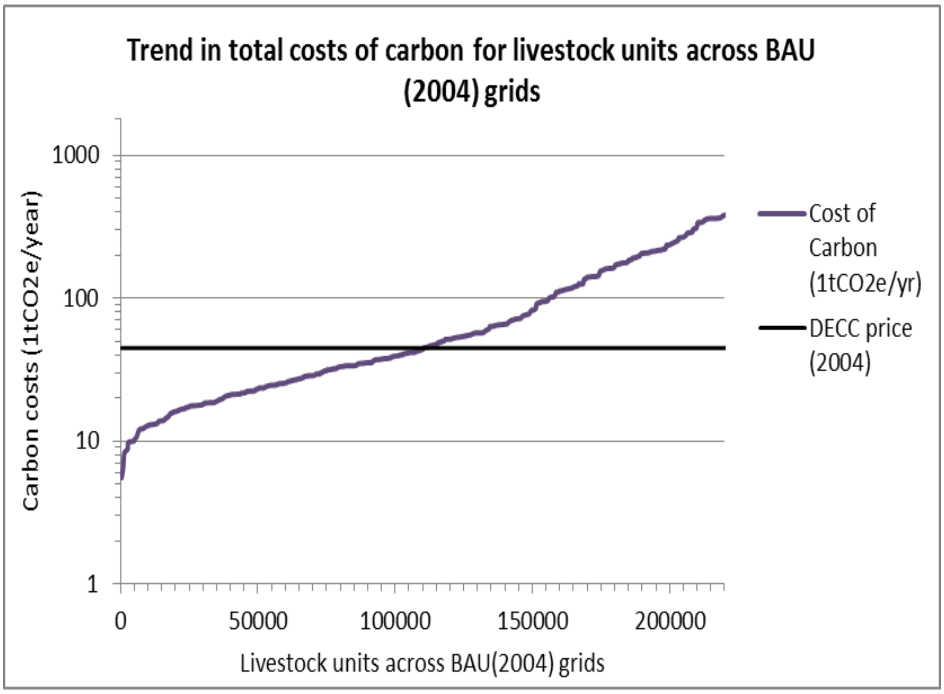


Figure 7.6 Comparison of carbon costs of the two potential schemes according to the accumulated annual emissions abated across grids for BAU (2004) year (tCO_2e/yr)

To further investigate the interdependence of carbon values and landscape features, carbon costs were plotted against livestock units and agricultural area from the BAU scenario. A DECC (2004) carbon price segment was added to the plots as a reference to investigate the distribution of carbon values within the DECC price range. To show the distribution clearly the carbon values were log transformed. The graphs illustrate that carbon costs within the DECC price range could lead to abatement of emissions from 120,000 livestock units (Figure 7.7a) and 45,000 ha of agricultural land (Figure 7.7b).



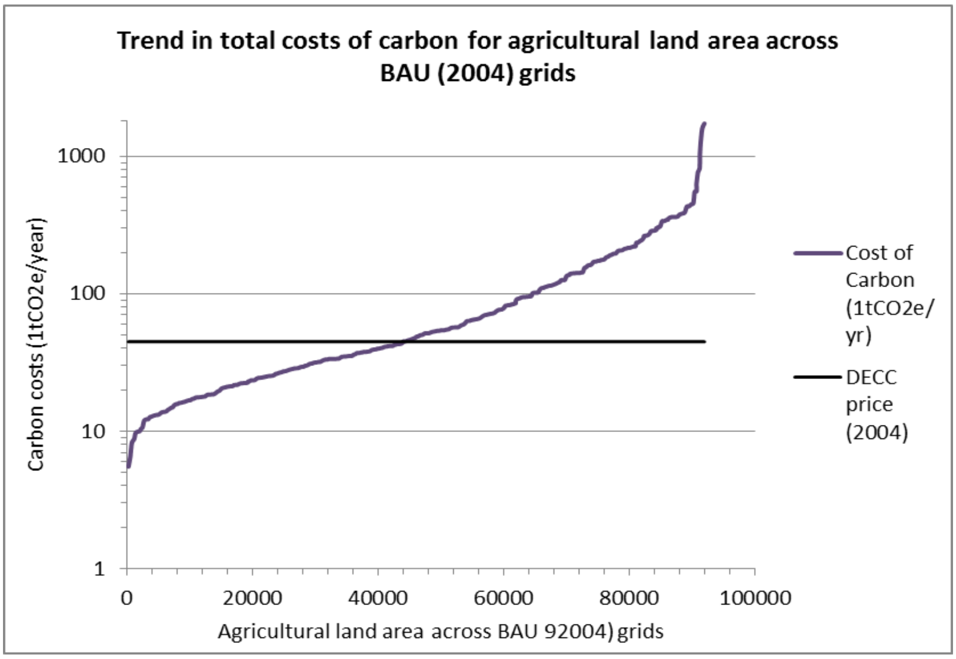


Figure 7.7 a & b Variation of carbon costs according to land use share and livestock units across UKNEA BAU (2004) grids

7.5. Discussion

Carbon abatement costs can be considered as an important aspect for designing climate change mitigation schemes, because a cost analysis can help to determine the effectiveness of a scheme and identify the abatement targets and associated compensations to make the scheme more favourable for participation. To achieve this aim, this chapter applies a marginal abatement carbon cost (MACC) approach along with spatial analysis.

The carbon valuation results for the mitigation scheme revealed a high variance in the carbon costs farmers associate with emissions mitigation through this scheme. The farmers show a resistant behaviour by requiring very high WTA although not much emission abatement is achieved. However, for the sequestration scheme the carbon valuation revealed that higher abatement can be achieved at fairly homogeneous compensations across the sample.

Carbon valuation for two alternatives for each scheme was also carried out to investigate preferences of farmers for different policy characteristics. The analysis revealed that on-farm AD (OFAD) plants are a cheaper option to attract farmers for mitigating manure emissions from livestock as compared to centralised AD (CAD) plants. This interest of farmers can be due to the potential benefits associated with the OFAD (such as revenue generation and reduction in utility bills for farm and house) and to avoid additional costs of transportation and arranging additional feed-stocks for larger CAD plants. Similarly for sequestration policy farmers show a preference for scheme alternative which requires lower and flexible land management activities. The comparison of the two alternatives revealed that if both schemes are introduced the farmers show a preference for the lower intensity scheme; however, it remains cost-effective only to a certain level after which the higher intensity scheme becomes more cost-effective. This shows that in order to implement such schemes effectively, it is important to have clear and pre-defined abatement targets.

Overall the cost analysis revealed that scheme using agroecosystem to sequester carbon can prove to be a more efficient approach for attracting farmers, to achieve the climate change mitigation targets through agricultural systems. This can potentially be due to no or lower costs for adopting changes in land use and management activities compared to the higher costs, skills, and effort associated with technologically advanced measures.

A comparison of the carbon costs with the DECC (2009) price revealed that the carbon costs associated with the sequestration policy are more in line with the DECC price than the mitigation policy and almost half of the sample was willing to sign up for a scheme at a price below or equal to the DECC (£44.6/tCO_2e) price.

Regression analysis was also conducted which helped to identify the target groups of farmers to whom it will be cheaper to implement abatement schemes. The analysis showed that farmers with higher number of livestock units and large farm size in terms of arable land associate lower carbon values and show a positive preference towards participation in carbon abatement schemes. This is in agreement with existing literature (Ayuk, 1997; Caveness and Kurtz, 1993; Thacher *et al.*, 1997) that farm size is positively related to the willingness to participate in payment schemes and is suggested that larger land holdings lead to greater flexibility towards the land manger's decision to participate (Nowak, 1987).

Furthermore, a spatial analysis was conducted using GIS to reveal the areas of higher mitigation potential at a lower carbon cost. It was displayed that carbon abatement schemes would be cheaper if implemented in the Southern parts of the UK as compared to the North of England and Scotland. This is comparable to the UKNEA (Abson *et al.*, 2013) carbon estimations and predictions for enclosed farmlands. The UKNEA calculations predicted that carbon costs in England would increase from £100 per hectare from BAU year (2004) to around £480 per hectare in 2060 and around £800 a hectare in Scotland and Wales. If the estimations of this study are simulated over time, the costs for the current research would show a similar pattern of increase across the regions.

7.6. Conclusion

In this chapter carbon valuation was conducted for the policy schemes designed for the CE study presented in the preceding chapters (5 & 6). A marginal abatement carbon cost (MACC) approach was employed for estimating the carbon values. The two schemes were compared according to their cost-effectiveness. The study also explored the spatial pattern of the carbon estimations linking them to farm and landscape characteristics.

The carbon costs evaluations revealed that a scheme involving carbon sequestration through changes in agroecosystems is cheaper to implement than a scheme based on AD technology and farmers prefer policy schemes which are less intensive in terms of costs and effort. This was evident from the preference of farmers towards OFADs rather than CADs.

Overall the costs of the carbon abatement are relatively high compared to the DECC price (£44.6/tCO_2e) but the analysis also suggested that half of the sample was willing to sign up to a scheme at a price below or equal the DECC price. Carbon values for sequestration policy were more in line with the DECC price than the mitigation policy. Therefore, the results suggest that sequestration policy will be a more attractive option to be taken up by the UK farming community, and be more cost-effective.

GIS have been widely used for environmental planning research and environmental valuation studies. Analysing spatial heterogeneity and distribution of economic values allows policy makers to extract values for any specific ES and area, easily to evaluate potential policy measures. The spatial analysis of the carbon values also revealed the regional distribution of the carbon costs and suggested that the North of England and Scotland prove to be more expensive than the rest of the regions included in the sample survey.

Furthermore, regression analysis was conducted to explore and predict changes in carbon values in accordance with different landscape attributes. It was revealed that farmers with higher livestock units and larger arable land can be a potential target group which could be effectively attracted towards policies as they have lower costs of provision of carbon abatement.

The study presented in this chapter contributes to the carbon valuation literature by providing carbon abatement costs based on real data from a CE study. The work reported is the first to use stated preference welfare estimations for carbon valuation of potential policy schemes for enhancing climate regulation service in UK agricultural sector. It also adds to the literature by providing a comparison of a technologically advanced scheme to a scheme with natural course of action in terms of their cost-effectiveness.

In summary, this chapter provides carbon costs for implementing potential payment policies both for emissions mitigation and carbon sequestration. The study provides a comparison of the cost-effectiveness of the two schemes. It provides an overview of the preferences of farmers in terms of the carbon values they associate with their preferred choice of land use change measures and farm management options. Finally spatially mapping the individual carbon values associated with each farm of the sample enabled the identification the target groups and locations for effective implementation of such policies. This chapter therefore explored the carbon costs UK farming community associates with additional tonne of carbon which can be potential abated from their farms.

The following chapter will conclude the thesis by highlighting the synthesis of the empirical work conducted to build this thesis. It will also provide the scientific contributions and policy relevance of the works along with limitations and future research work.

Chapter 8 Synthesis and Conclusion

8.1. Introduction

Research addressing incentive policies for the protection and conservation of ES from agroecosystems have been exploring the design of schemes (payment schemes) (Birol and Cox, 2007; Espinosa-Goded *et al.*, 2009; Ruto and Garrod, 2009), investigating the preferences of farmers (Beharry-Borg *et al.*, 2012; Garrod *et al.*, 2012; Kosoy *et al.*, 2008; Wilson, 1997), and exploring the spatial variation of the preferences in terms of the associated values (Balderas Torres *et al.*, 2013; Broch *et al.*, 2013; Brouwer *et al.*, 2010; Campbell *et al.*, 2009). Nonetheless, in many cases such efforts have been limited in their focus towards a single aspect (either on the design or the preferences). This thesis assesses the scope of UK agroecosystems' contribution towards the UK's climate change mitigation targets. It provides a detailed assessment of the climate regulation service provided by the agroecosystems and the scope for designing payment policies for farmers by taking all the aspects mentioned above into account. It consists of four main analytical components reported in Chapters 4, 5, 6 and 7.

This Chapter starts with an overview of the key analytical approaches for executing each of the components and the major findings generated from each (Section 8.2). Section 8.3 highlights the key contributions of the overall research, followed by a discussion of the limitations of the research (Section 8.4). Future research arising from this study is outlined in Section 8.5 and the chapter ends with some overarching conclusions from the research.

8.1. Summary of key analyses

This section provides an overview of the research approaches employed for achieving the key objectives of the thesis along with the key findings of each analytical component.

8.1.1. Objective 1 - Estimating changes in climate regulatory service

To explicitly model land use related agricultural GHG emissions under high and low UK Climate Impacts Programme (UKCIP) emissions scenarios for the period 2004-2060.

This objective was addressed in chapter 4 of the thesis and contributed to the UKNEA project to evaluate the changes in regulatory services due to land use changes. The analysis includes estimations of both changes in potential carbon stocks and annual flux of GHGs. The changes in land uses were derived from a spatially explicit land use model developed by Fezzi and Bateman (2011) and were based on UKCIP low and high GHG emissions scenarios for years 2004 (BAU year), 2020, 2040, and 2060. The analysis included the three main GHGs; CO_2, N_2O, and CH_4. The calculations of the stocks and flows of the GHGs were based on data collected from a review of existing literature.

The soil organic carbon (SOC) stocks were estimated for various soil types and land uses while the biomass organic carbon (BIOC) stocks were estimated based only on land use. The land use types included in the analysis were cereals, oil seed rape, root crops, temporary grassland, permanent grassland, rough grazing and farm woodland and the livestock types included were dairy cows, beef cattle, and sheep.

The GHG flux was estimated for various land use and management activities. CO_2 emissions were estimated for both direct sources (changes in soils and vegetation carbon) and indirect sources (agricultural activities such as tillage, sowing, fertilizer and pesticide application, harvesting, and bailing). N_2O emissions were calculated for fertilizer use, manure of livestock; both as slurry and direct input from grazing livestock and for the emissions from the land use types according to the nitrogen requirements from inorganic fertilizers. CH_4 emissions were estimated for enteric fermentation from livestock. GHG fluxes from land use change were calculated both for annual SOC fluxes and biomass, due to land use changes.

The total UK vegetative carbon stocks for the baseline year (2004) were estimated to be 134MtC, which are in agreement with Milne and Brown's (1997) estimate of 113.8±25MtC. The GHG fluxes for the baseline year were estimated to be 35MtCO_2e which are comparable with official estimates of GHG emissions for 2004 which range from 44.53MtCO_2e (Thomson *et al.*, 2007) to 51.7MtCO_2e (Yearley, 2009).

The estimations under the two UKCIP emissions scenarios revealed large regional variations in annual emissions within enclosed farmlands habitat across UK. It indicated that northern parts of the UK are expected to see a decrease in potential carbon stocks and rising GHG emissions due to increased livestock numbers and increase in arable and horticultural production as the climate warms. Conversion of agricultural land on organic soils from rough grazing to improved, temporary, and permanent grassland would also contribute to increased GHG emissions. The southern parts are predicted to see small increases in carbon stocks and associated falls in annual agricultural emissions because of a shift from cereal cropping towards grasslands.

Overall the analysis revealed that aggregate changes in all the analysed years were relatively small with the exception of 2060 under the UKCIP high emission scenario where predicted conversion from arable to grassland on organic soils resulted in considerable net accumulation of SOC.

The analysis also illustrated that adjustments in land use and management can help to mitigate GHG emissions from agriculture. The study suggested that agroecosystems have the potential to contribute towards climate change mitigation. The evaluation served as a concrete starting point for thinking about the potential of agroecosystems for achieving emissions reduction targets and concluded that climate change directly or indirectly is likely to cause changes in the carbon stocks through land use change. The analysis suggested that climate change will reduce the capacity of agroecosystems to regulate carbon emissions; however some adjustments in land use will help to reduce emissions. The heterogeneity in land use and land use change, and associated changes in emissions leads to a need to explore the scope of designing policies for land managers to adopt changes in land use management. In order to explore this scope, it is imperative to investigate farmers' land use decisions and how these would affect their participation in potential policy schemes. This constituted the second objective of the thesis.

8.1.2. Objective 2 – Heterogeneity in farmers preferences

To investigate land owners' attitudes and preferences towards payment schemes for enhancing climate regulation (through emissions mitigation and carbon sequestration) and suggest scheme design for developing effective policies for attracting farmers to contribute towards the UK's carbon abatement targets.

This component of the research, presented in Chapters 5 and 6, aimed to evaluate potential PES scheme design for enhancing climate regulation service provided by farmlands. This research stage explored the potential of payment schemes to contribute towards reductions (increases) in emissions (carbon sequestration) and investigated their uptake by UK's farming community. A stated preference approach, Choice Experiment (CE) was employed to elicit farmers' choices for two potential payment policies, respectively designed for arable and livestock farming landscapes. One scheme was targeted towards reduction of GHG emissions from livestock manure (Chapter 5) with the other for enhancing carbon storage in agricultural land (Chapter 6).

The analysis involved ex-ante evaluation of farmer uptake based on attributes of the two schemes by analysing the impact of different attributes and attribute levels on their participation behaviour. Hence, the first step was to define the policy schemes in terms of suitable attributes and levels. The data was collected using structured questionnaires containing the choice experiments to reveal farmer preferences. CLM, RPL, and LCM were employed to investigate the preference heterogeneity and willingness of farmers to accept compensation for adopting changes in land use and management activities.

The analysis revealed that farmers show an overall aversion to drastic changes in their land use management activities however, they can be encouraged to participate in payment schemes by providing appropriate compensation incentives and adjusting required levels of change. The results suggested that farmers would prefer to participate in schemes with flexible and less restrictive measures. The CLM and RPL estimations for both the schemes suggested preference heterogeneity which was further explored by using LCM.

For the mitigation payment policy the results revealed that larger farms and farms with higher livestock units prefer OFADs. The results indicated that age, farm size, livestock units, and farm income influenced farmers' participation preferences, and indicated that younger farmers and farms with larger farm size would require lower compensation payments. Farms with larger number of livestock units were found to be less averse to longer contracts, while low income farms revealed a stronger preference for on-farm AD plants. The WTA was the highest for ownership of the plant, revealing that farmers want to retain management control.

The sequestration payment policy results revealed that farmers were very averse to restrictions on grazing time period and conservation ploughing which was also affirmed by the WTA estimates. The socio-economic interactions with the attribute coefficients were unable to provide any significant information about the determinants of farmers' preferences for this policy.

The analysis presented in these two chapters was intended to identify the preference heterogeneity of farmers; however, most of the heterogeneity was not explained by the farm or farmer characteristics. Nonetheless, it is still important to know the range of behaviours among farmers when assessing likely uptake of policy schemes for enhancing the provision of climate regulation service.

8.1.3. Objective 3 – Spatial patterns of carbon values

To calculate carbon abatement costs for potential payment schemes and provide an analysis of the spatial pattern of the carbon abatement costs through PES schemes across the UK.

This comprised the final stage of the PhD thesis which combined economic valuation and spatial mapping to illustrate the cost-effectiveness of potential payment schemes and spatial distribution patterns of the estimated costs. A marginal abatement cost method was employed to calculate the costs of carbon in terms of the costs of reducing carbon emissions by adopting alternative policy scenarios. The carbon abatement estimations were combined with WTA estimates from the CE study conducted for objective 2. The cost analysis was followed by statistical analysis to explore the linkage to farm/farmer characteristics. This analysis revealed that farmers with more arable land and higher number of livestock units have lower costs for the provision of carbon emission mitigations. This was followed by a spatial analysis to further explore the spatial distribution of the carbon costs. Land use maps generated for objective 1 were employed for the spatial analysis and linked to the data for the regional grids to associating carbon costs with landscape attributes. The results of the carbon valuation revealed that sequestration policy scenario proved cheaper to implement compared to the mitigation policy scenario and farmers associate lower costs for policies with lower intensity of the required measures. Spatial mapping of the carbon costs at regional level illustrated that achieving carbon reductions in northern parts of England and Scotland proved costly as compared to the southern parts. This is potentially because the cost of achieving carbon abatement through carbon sequestration policy was found to be cheaper than mitigation policy, and the Southern regions of the UK contain substantial areas of farmlands.

Since the DECC price is the UK's official non-market carbon price, the carbon costs estimated were compared with the DECC (2004) price. The comparison revealed that half of the sample respondents were below £44.6/tCO_2e (DECC 2004 price), suggesting that carbon abatement initiatives in agriculture could be good candidates for the UK to meet their emission reduction targets. Regression analysis for the determinants of the carbon costs revealed that farms with larger arable land and livestock numbers have lower carbon costs. These farms are therefore particularly relevant to consider when designing policy schemes.

8.2. Key contributions

This PhD thesis employed a novel approach of assessing the scope of payment scheme policies for enhancing climate regulation services provided by the UK agroecosystems. It evaluates the contribution of agroecosystems towards climate change (both in terms of services and disservices) and assesses the scope of enhancing the ability of agroecosystems within a single comprehensive study. The three analytical stages of this research study generate empirical evidence and advancement in understanding the overall role of agroecosystems towards climate change. The overall framework can be applied to other countries and other ES.

Climate change research has identified the potential of agroecosystems to contribute towards emission reduction targets (Paustian *et al.*, 1997; Smith *et al.*, 2007b; Smith *et al.*, 2007c; Smith *et al.*, 2000) and the need for designing and implementing effective policies for attracting the farming community (Balderas Torres *et al.*, 2010; Smith *et al.*, 2007b). However, at present there is a gap in appropriate estimations and valuation of the climate regulation service from agroecosystems, effective design of incentives, and improvement of policies in terms of their cost-effectiveness. One of the contributions of this thesis (Chapter 4) is therefore in its provision of an updated account of the changes in regulatory service in terms of carbon stocks and GHG fluxes. Although it builds on the emerging literature of estimations of carbon stocks and GHG emissions, unlike most of the previous studies, the current study presented the estimations for three major GHGs such as CO_2, CH_4, and N_2O in a single study. The changes were estimated directly from land use changes and livestock (including manure) and indirectly from farm management activities. The results were comparable to most of the estimations in the existing literature (such as Bradley *et al.*, 2005). Another important contribution is the prediction of the impacts of land use changes on GHG emissions. Land use changes and their impact on agriculture have been addressed in the literature (Hediger, 2006; Moran *et al.*, 2010; West and Marland, 2003); however, not many spatially explicit analyses can be found for the evolution of GHG emissions associated with land use changes and which impact the GHG emissions across space even at relatively fine spatial scales. The current study (Chapter 4) accounted for this issue by using outputs from a structural econometric land use model at a fine resolution of 2km x 2km to explicitly model land use related GHG emissions under UKCIP high and low emissions scenario.

The second contribution of the thesis comes from the investigation of the heterogeneity in the preferences of farmers towards participation in potential payment policies (Chapters 5 and 6). This thesis contributes to the limited literature on estimation of costs of provision of climate regulation from UK farmlands by utilising a novel approach, combing two potential payment schemes for two distinct (arable and livestock) farm types. It is the first attempt to conduct such a study for two schemes (mitigation and sequestration) simultaneously.

Uptake of anaerobic digestion (AD) plants has not been very popular in the UK; therefore, this study contributes to the AD plant literature by assessing the preferences of farmers towards a mitigation policy scheme (Chapter 5). This provided an insight into the preferences of farmers towards various scales and types of anaerobic digestion plants. The study concluded that farmers show preference for small scale on-farm AD plants and prefer higher compensations (Chapter 5). Centralised AD plants could be an option for small farm holdings however, the cost-effectiveness study (Chapter 7) revealed that farmers associate higher carbon costs with CAD plants, which makes them a costly option.

The third important contribution of the thesis comes from the last stage (Chapter 7) of the PhD research which included the valuation of carbon abatement potentially achieved through the implementation of the two schemes designed in the second stage of the research. Unlike studies which estimate marginal abatement costs for individual measures (Moran *et al.*, 2008) this study provides a holistic approach by calculating carbon abatement costs for complete policies rather than measures. To the author's knowledge, it is the first attempt to compare the cost-effectiveness of a technologically advanced scheme with a scheme based on increasing the provision of an ecosystem service.

8.3. Policy implications

This research thesis, as mentioned earlier in the chapter, aimed to assess the scope of ES payment policies for agroecosystems' contribution towards climate change mitigation. The thesis was framed to provide information for policy makers regarding the economic magnitude and spatial distribution of carbon costs at micro (farm) level to derive better informed policies for ES conservation. Combining preference heterogeneity and spatial variability can prove effective in capturing individual preferences and can be helpful in this context.

It is clear from the research that agroecosystems are expected to undergo significant land use changes induced by climate change but also contribute towards climate change by releasing carbon and other GHGs into the atmosphere. The analysis shows that climate change may lead to significant changes in UK agricultural land use and these changes will lead to regional disparity in GHG emissions. This information is important to predict the changes in regulatory service provided by these agroecosystems and associated costs over time. These predictions can help to inform efficient policy design as it provides information towards the potential level of action required and suggests information regarding the associated compensation amounts that might be required to implement policies in the UK farming sector.

Climate change mitigation is considered to be difficult to achieve in the agriculture sector. It faces the challenges of permanence, leakage, and additionality (FAO, 2008). Permanence requires the emission mitigation to be sustained, additionality requires the mitigation to be additional to the current situation, and leakage, a more global issue, includes the increase of emissions elsewhere in the world through increased import of food. These challenges require policy makers to design policies appropriately. The two policy schemes proposed in this study address the permanence and additionality issues by offering land use management activities which can be sustained over a longer time period and by asking land use managers to adopt these activities in addition to their current management practices. Furthermore, leakage can be avoided by proposing policies which do not affect the food production of farms locally and hence reduce the need to import food. The proposed mitigation policy does not have any effect on the food production however, the sequestration policy, proposes conversion of land to permanent grasslands and for afforestation, which will eventually reduce the productivity of farms. Hence, this research highlights the need to design policies for climate change mitigation in a more global context.

The study also suggests the need for framing regional policy according to the level of action required. The study predicted a significant agricultural intensification in the northern parts of the country which will eventually lead to an increase in GHG emissions and loss in carbon stocks. On the other hand, the results of the estimations and predictions in changes in regulatory service also suggested that in some regions climate induced land use changes, for example, conversion from arable to grasslands in the southern parts of the country, can also have positive impact on GHG mitigation. The estimations from the CE study revealed that farmers prefer to enrol smaller percentages of land for conversion to grassland and afforestation, and the carbon valuation study also revealed that farmers do not require high costs for the provision of carbons sequestration in their arable land.

The investigation of the potential scheme design and the preferences of farmers towards these schemes presented empirical evidence that farmers are heterogeneous in their behaviour. The socio-demographic factors that have a significant effect on the participation behaviour of the farmers included age, farm income, farm size, and livestock units. Investigating the effect of the attributes of the policy revealed that farmers are averse to drastic changes and would prefer policies which require lower levels of action and allow certain flexibility over measures.

For the mitigation policy scheme, the study suggested that targeting on-farm AD plants towards larger farms with higher numbers of livestock along with appropriate compensation has the potential to attract farmers towards the uptake of such plants. Lack of technical assistance or training was identified to be one of the reasons for the closure of AD plants in the UK (Bywater, 2011). This study also revealed the importance farmers associate with this attribute and suggested that policies ensuring the provision of technical assistance (training) will have a better chance of attracting more farmers. An additional policy relevant conclusion obtained from the estimations of the mitigation policy is that even though ‘generator capacity’ was not significantly considered by the respondents, it is still important to factor it in when designing policies related to AD.

It is known that carbon sequestration requires longer time scales; however, the investigation into the carbon sequestration scheme revealed that farmers prefer short term contracts over long term policies. Hence, there is a need to design policies with measures which are easily sustainable over a longer time period and farmers can continue with them even after their contracts. Investigation into the preferences of farmers towards the sequestration scheme attributes suggested that schemes requiring the farmers to adopt extensive grazing and conservation ploughing did not prove popular among the farmers.

The study of farmers’ attitudes suggests that schemes designed for enhancing climate regulation service provision need to factor in the characteristics of the farmers and their farms as these partially determine participation. Although most of the preference heterogeneity from farmer characteristics was not observable i.e. only farmers’ age was significant; farm characteristics such as farm income, farm size, and number of livestock units were revealed to influence their preferences significantly. The study also highlighted that accounting for preference heterogeneity captures additional diversity in carbon costs, which has a significant influence over the predicted impact of scheme policy initiatives.

The last analytical stage of the thesis explores the cost-effectiveness of the two potential schemes. This helped to provided predicted costs of implementing the payment programmes for farmers to change their land management practices, to achieve the required climate change abatement. The analysis revealed that sequestration policy scheme, which does not have any costs of uptake is cheaper to implement. This suggests that policy makers can focus more on schemes for carbon sequestration by land use change rather than schemes which involve adoption of technology.

Regional analysis illustrated that it will be much cheaper to implement sequestration policies in the southern regions of the UK. A comparison with the DECC price helped to identify a reasonable price range to attract farmers towards emission reduction policies. The spatial analysis explored the spatial patterns of the carbon costs and its linkage to farm and landscape characteristics. This analysis revealed the locations of the target groups i.e. least resistant farmers in terms of carbon costs. This finding is helpful for the policy makers to target policies schemes effectively.

Overall this research suggests that future policies should be based on assessments of the attitudes and behaviour of the farmers, which influence their decisions of taking up polices schemes. It provides some guidance by quantifying farmer heterogeneity and potentially identifying certain farm and farmer characteristics as determinants of farmers' participation behaviour. Using valuation techniques and GIS together the thesis allowed to model the spatial variation in the carbon costs which is particularly relevant for appropriate targeting of policy schemes.

8.4. Limitations and future directions for research

This section discusses the limitations and challenges faced by this research study. Some of the issues encountered were realised in the later stages of the research and therefore, can only be addressed in future studies. The following list provides the limitation of this research and some future ideas that can be followed up in future studies to address the identified issues:

1. Getting and establishing contacts with farmers was extremely difficult. Various farmers' associations were contacted to establish some connections to farmers but they were reluctant to share any information on the basis of confidentiality. Consequently as attempt was made to conduct the survey at farmers markets in order to conduct face-to-face survey cost-effectively and to have a representation of various farming landscapes in the UK. However, this was not very fruitful, since not many farmers participated in such markets. Alternatively, the survey was conducted at livestock auction markets and dairy and livestock expos. Although, this helped to conduct the required number of questionnaires as per the CE design; however, it failed to obtain a representative sample.
2. One of the policy scenarios explored the uptake of AD plants for mitigation of GHG emissions from livestock manure. 'Generator capacity' is an important attribute which determines the size and eventually the investment costs and revenue generated from these plants. However, as evident from the model estimations (Chapter 5) this attribute was not significantly considered by the respondents. This could be because of not enough information regarding the capital investment options provided to the respondents. Therefore, future research needs to better explain this kind of policies so that the respondents can better understand the importance of each attribute.
3. The model estimations also revealed a status quo bias (as discussed in the respective chapters). Although there are various reasons for this bias, for

this research the plausible explanation for this bias could be yea-saying to please the interviewer. However, this issue was realised in the much later stages of the PhD and could not be addressed at the time. Future research studies can take this into consideration at the survey design stage of by adding follow up questions to verify the consistency in the choice decisions of the respondent.

4. The GHG abatement calculation for AD plants (Chapter 7) only included the emissions from livestock manure and not additional feedstock which might be required depending on the size of the plant. Including the information about the size of the plants and the required additional feedstock can help to increase the accuracy of these estimates.
5. An up-scaling study across the UK for the spatial analysis could not be carried out as the sample was not representative enough at regional levels. This was due to limited time scale and budget for the fieldwork carried out for this study and also due to lack of contacts with farmers. A much improved representation of farmers could provide enough potential for a national scale study.

8.5. Concluding remarks

The climate regulation service provided by agroecosystems has the ability to help towards achieving climate mitigation targets. Incentive policies such as PES have the potential to provide a strategy of linking ES to land managers. This research thesis assessed the scope of PES policies to enhance the regulatory service provided by UK farmlands. The research focused on enhancing services (carbon sequestration) and mitigating disservices (GHG emissions) from farmlands. The research adopts two approaches to explore land managers preferences for policy alternatives. The first approach is an investigation into the heterogeneity in farmers’ preferences for land-use changes by determining the influence of socio-economic factors and policy attributes. The second approach provides a cost-effectiveness analysis of hypothetical policy alternatives and the spatial distribution of the values obtained. These two approaches helped to provide an understanding of climate regulation service provision and land managers' decisions required for better informed policy formulation. Overall, the outcomes of this PhD research lead to the recognition of the potential contribution of agroecosystems towards climate mitigation targets, and the increase in the challenges faced due to climate change. It also identified the importance of correct policy formulation and appraisal for ES conservation. At the same time it highlights the need for using economic valuation and spatial mapping for efficient implementation of policies, since agroecosystems are spatial diverse in nature. Finally, it is hoped that this thesis would contribute to strengthen and advance the literature regarding PES policy schemes, ES valuation in general and provide a direction for policy decisions in particular for achieving some of the UK's emissions targets from agricultural land.

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APPENDICES

Appendix A: Experimental design and description of the questionnaire survey

The administration of the choice experiment surveys for both payment scheme scenarios along with the survey design is described in this appendix. The main objective of the survey was to investigate farmers' preferences and their attitudes towards different design options in two specific payment schemes respectively aimed at enhancing the mitigation of GHG emissions and carbon sequestration in the agricultural sector. The experimental design consisted of four main stages: (1) developing two hypothetical scheme scenarios for both arable and livestock farms across the UK farmlands (2) selecting the attributes and levels for the choice sets for both the policy scheme scenarios (3) choosing the experimental design and constructing the choice sets and (4) developing the questionnaire for the field survey. The design of the survey was carried out in such a way as to minimize any biases that may prevail. The two payment scheme policies were developed after a detailed study estimating the changes in regulatory service provided by UK farmlands due to land use changes conducted as the first stage of this PhD research (chapter 4). This appendix presents the statistical design adopted to generate the choice cards and combinations for the CE survey. It also provides a detail of the sections of the questionnaire, and followed by a complete version of the survey questionnaire.

Introduction

The first step for CE design is to identify the attributes and their levels for the ES under scrutiny, which in this case is enhancing the climate regulation service provided by the UK farmlands. Significant attributes were identified and their levels were chosen to be realistic and represent possible future values if policy measures were to be implemented (Bennett and Blamey, 2001[14]). The range of levels was selected so as to represent each attribute according to the size and scale of the improvement that farmers are willing to carry out.

The choice and selection of the attributes and levels was based on a combination of evidence from the findings in the existing literature on agri-environment schemes across Europe and information from the pilot study of this research. Both potential payment scheme scenarios designed for this study were described in terms of 6 attributes each, with two common attributes including length of contract and payment per hectare. The payment attribute was included to determine the Willingness to Accept (WTA) of the farmers to participate in potential schemes. This provides an insight into how farmers trade-off the changes in land management activities required by the schemes for the provision of climate regulation services. Each choice card presented to the farmers had two policy alternatives offering different combinations of the levels along with 'I do not want to participate' (that is the status quo). The underlying assumption was that the selection of the alternatives and attributes would help to provide an understanding of the preferences of the farmers towards agri-environment schemes for enhancing the climate regulation service of UK farmlands.

Pilot study:

CE pilot studies are conducted at a small scale before the main survey in order to test the questionnaire and choice experiment design. This also helps to determine if the survey is easily understandable and interpretable by the respondents and if any changes need to be made in any part of the survey. The pilot for this study was conducted by visiting farmers' markets. Thirty pilot questionnaires were conducted by visiting farmers' markets in Northallerton, Otley, and Doncaster. During this pilot the participants were asked whether they considered all the attributes presented to them and to provide feedback about the questionnaire. This revealed that all the

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14 Bennett, J. W. & R. K. Blamey, eds. 2001. 'The choice modelling approach to environmental valuation'. Edward Elgar Publishing Limited.

participants were aware of the attributes and levels provided to them and they had considered most of the attributes while selecting the scheme alternatives. The attribute that received the most attention in both the scenarios was the 'compensation' being offered to them to adopt the changes in their land use management activities. Other attributes mostly considered for the mitigation scenario were; 'technical assistance', and 'distance' while for the sequestration scenario the attributes considered were; 'percentage of land allotted for conversion to grassland', 'percentage of land allotted for afforestation', and the 'grazing time period'. The choice responses from the pilot study were then analysed using simple conditional logit model to determine if the results made logical sense. As already stated the main objective of the pilot study was to tailor the questionnaire and choice cards in a very effective way before conducting the actual survey of the study.

A description of the attributes for each of the scheme scenarios is presented in Chapters 5 and 6 of this thesis.

Experimental Design

After identifying the attributes and levels of each policy scheme, an experimental design was constructed in order to generate the choice cards with different combinations of choice attributes and levels. This helps to maximize the amount of information that can be obtained from the respondents (Lusk and Norwood, 2005[15]). Experimental designs are the foundation of stated preference methods (Hensher *et al.*, 2005[16]) and the research phase for researchers to manage and manipulate attributes and levels. CE assumes that goods/services to be valued can be described by their attributes and the levels of these attributes (Lancaster,

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[15] Lusk, J. & F. Norwood. 2005. Effect of experimental design on choice-based conjoint valuation estimates. *American Journal of Agricultural Economics,* **87**, pp.771-785.

[16] Hensher, D. A., J. M. Rose & W. Greene. 2005. 'Applied Choice Analysis: A Primer.'. Cambridge: Cambridge University Press.

1966[17]). Respondents are presented with several choice sets, each composed of several competing options, and the respondents are asked to choose the one option they prefer the most. Experimental design techniques were first introduced in multi-attribute stated preference methods by Louviere and Woodworth and Louviere and Hensher, in agricultural and biological experiments to derive and predict choices (Ferrini and Scarpa, 2007[18]). Through this they identified a set of choices which are described on the basis of selected attributes and levels, which are arranged in an orthogonal fashion. If the choice sets are too numerous for evaluation in a single choice context they are divided into manageable series of choice sets using blocking techniques (Ferrini and Scarpa, 2007). This process ensures that attributes are statistically independent.

An important consideration when choosing an experimental design for a CE is to maximise orthogonality and balance (Lusk and Norwood, 2005). *Orthogonality* requires that the attributes are uncorrelated with one another across the design. *Balance* means that each level has the same statistical power and occurs with equal frequency. To achieve this, a full factorial design can be used which consists of all possible combinations of attributes and levels and allows for estimation of main effects[19] and interaction effects[20] independently of one another. However, using a full factorial design sometimes is not practical and cost-effective as it produces large number of surveys (Louviere *et al.*, 2000[21]). Given that, fractional factorial designs are usually implemented. The fractional factorial design is in reality a sample of the

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17 Lancaster, K. J. 1966. New approach to consumer theory. *Journal of Political Economy,* **74**, pp.132-157.

18 Ferrini, S. & R. Scarpa. 2007. Designs with a priori information for nonmarket valuation with choice experiments: A Monte Carlo study. *Journal of Environmental Economics and Management,* **53** (3), pp.342-363.

19 Refers to the direct effect of each independent variable on the dependent variable.

20 Effect of the interaction between two or more independent variables on the dependent variable.

21 Louviere, J. J., D. A. Hensher; & J. D. Swait, eds. 2000. 'Stated Choice Methods-Analysis and Application'. Cambridge University Press.

full design which allows estimation of all the relevant effects. Full and fractional factorial designs can also be blocked into different versions. For blocking a design a new orthogonal column is added to the design, which divides the whole design into different blocks (depending on the levels of that added column). Each block is then randomly assigned to the respondents. Researchers have also developed statistically efficient designs called as ‘optimal designs’. The main objective of an optimal design is to create a design which optimises the amount of information obtained from the choice sets, i.e. they are statistically efficient. However, it has the problem of correlation between the attributes.

For this study, in order to generate the choice cards with different combinations of choice attributes and levels, a full factorial design was first generated. The total number of choice sets resulting from this was $4^4 + 2^2 = 260$. This large number of combinations, was considered not feasible to be used, therefore, an orthogonal fractional factorial design was generated using Ngene 1.0.2., which resulted in 36 choice sets. Since this is quite a large number of information to be presented to one respondent, a blocking strategy was employed to reduce the number of choice sets given to each respondent. Blocking basically involves introducing an orthogonal column to the design, whose attribute levels are then used to segment the design (Hensher *et al.*, 2005). For each of the payment scheme scenarios 36 choice sets were then blocked into 6 blocks of 6 choice-sets each. Using this, each respondent was presented with 12 choice cards for both the scenarios (6 for each scenario). Therefore, 6 farmers were required to complete one entire run through the full CE design.

Sample size

Appropriate sample size can be determined in various ways. Studies like Bennett and Blamey (2001) and Louviere *et al.* (2000) have suggested the minimum guideline of 50 respondents. However, for this study the sample size was determined by using the guideline provided by Johnson *et al.* (2006)[22], which includes the number of levels of attributes (NLEV), the number of alternatives per choice (NALT) and the number of choice questions per individual (NREP).

$$N = 500.\frac{NLEV}{NALT.NREP}$$

Based on this guideline the minimum sample size calculated for this study was 334.

Field surveys

The survey was designed to cover the main farming landscapes in the UK which include uphill farms, dairy farms, mixed farms and arable farms and was conducted From July to November 2011. The survey locations were strategically selected at various locations spread across Yorkshire, Midlands, Norwich and Scotland. The underlying idea for the survey was to have a sample representative of the major UK farm types at the national extent. To achieve this within a limited time scale and budget, the researcher chose to visit farmers' markets. However, not many farmers participated in those markets; therefore, various other places like livestock auction markets, an annual farming expo and an annual international dairy and livestock event were selected to carry out the survey. This helped to conduct 380 face-to-face questionnaires in a cost-effective way. A research assistant was also hired who helped not only in conducting the surveys but also in transportation to different towns and cities. Some parts were also accessed by using the train service.

Sections of the questionnaire

The questionnaire contained three sections which helped to gather choice experiment responses along with socioeconomic information (including age, gender, education, household size, income sources and farm-specific information

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[22] Johnson, F. R., B. Kanninen, M. bingham & S. Ozdemir. 2006. '*Experimental design for stated choice studies* in Valuing environmental amenities using stated choice studies, chapter 7'. pp.159-202.

such as farm location, farm size, tenure management, type of farming, livestock and land management activities) of the respondents and attitudinal data regarding agricultural management activities and climate change.

For the CE survey, all respondents were first presented with an information sheet introducing the researcher and describing the context of the survey. Then they were given the chance of asking any questions they had, before they participated in the survey.

This section includes a full description of the questionnaire followed by a complete version of the questionnaire presented to the respondents.

Introduction

The enumerator approached the respondents by first introducing herself and informing them that she was a student from University of Leeds, carrying out research by surveying farmers in different parts of England. The respondents were presented with an information sheet, containing information about the researcher and the research project and the requirements and nature of participation. Then the respondents were asked if they would be willing to participate in the survey. If they agreed, a consent form was presented to them to be filled and signed by both the enumerator and the respondent.

Section A - Land use management activities

The first section of the questionnaire consisted of questions regarding the land use management activities being carried out by the respondent at his/her farm. First, they were asked if they were landowners or tenants and how much total land area they managed. Then they were asked about the land use types (root crops, cereals, oil seed rape, grasslands, etc), the number and type of livestock, tillage practices, application of fertilizer (farmyard or inorganic), and participation in any PES schemes.

Section B - Ranking statements

In this section the respondents were presented with statements regarding agricultural activities and their effect on reducing GHG emissions and were asked to rank them according to their preference. This helped to explore the respondent's attitude towards GHG emissions and impacts of agricultural activities on it. The respondents were also asked questions to determine their attitude towards GHG emissions in the UK and how agriculture can play a role in reducing these emissions. They were also asked about their contribution (if any) in this aspect.

Section C - Choice Cards

In this section the respondents were presented with an explanation of the policy scenarios along with a description of the attributes and the levels. Once the respondents understood both the scenarios well, they were asked to proceed to the choice cards. The respondents were presented with 12 choice cards in total, 6 choice cards each for each scenario. They were asked to consider all the attributes and then select one of the three alternatives provided to them in each of the choice cards, which best suited their farm situation.

Figure: A sample choice card for the mitigation scenario

<table>
<tr><th>Attribute</th><th>Alt_1</th><th>Alt_2</th><th>Alt_3</th></tr>
<tr><td>Generator Capacity</td><td>50kW</td><td>2MW</td><td rowspan="6">I do not want to participate</td></tr>
<tr><td>Distance</td><td>~5 km</td><td>15 km</td></tr>
<tr><td>Length of Agreement</td><td>2 years</td><td>20 years</td></tr>
<tr><td>Technical assistance/Training</td><td>Yes</td><td>No</td></tr>
<tr><td>Plant ownership</td><td>Own the plant</td><td>Handover to electric company</td></tr>
<tr><td>Compensation (£/ha)</td><td>£50</td><td>£25</td></tr>
<tr><td>I would choose to participate in</td><td>☐</td><td>☐</td><td>☐</td></tr>
</table>

Figure: A sample choice card for sequestration scenario

Attributes	**Alt_1**	**Alt_2**	**Alt_3**
Area of land converted to permanent grassland	15%	50%	I do not want to participate
Area of land for afforestation	5%	15%	
Grazing time periods	Only spring grazing	Intensive grazing	
Ploughing methods	Conservation till	Conventional till	
Length of agreement	2 years	20 years	
Compensation (£/ha)	£50	£25	
I would choose to participate in	☐	☐	☐

A full version of the choice cards for both the scenarios is attached as Appendix c.

Section D - Follow up

After the completing the choice cards the respondents were presented with a set of follow up questions. The basic motive behind these questions was to determine the main rationale behind their behaviour when making their choices. They were asked questions to determine the main reason behind their participation or non-participation in the payment schemes presented to them.

Section E - Socioeconomic characteristics

This section contained questions which helped to identify the socioeconomic characteristics of the individuals. All respondents were asked questions about their education, age, number of people in their household, sources of income, income, and their farm addresses. The respondents were assured that all their information would be kept private and anonymous. At the end all the respondents were also asked to provide their opinion about the survey, whether positive or negative.

Questionnaire for farmers and sample choice sets administered per respondent

SECTION A: LAND MANAGEMENT ACTIVITIES

1. Which of these describe you the best? [CHOOSE ONE ANSWER ONLY]

I am the land owner of all the land I manage	1
I am employed to manage the land	2
Other (Please specify)	3

2. What is the total area of farm land that you manage? ....ha

3. What is the total area of land that you own? ....ha

4. How long have you been managing this land? ....

5. What percentage of the land that you manage is:

Land use	Percentage/ha
Root crops	
Cereals	
Oilseed rape	
Temporary grassland	
Permanent grassland	
Forest	
Set-aside	
Other (Please specify)	

6. What cultivation techniques (e.g. Conventional till, conservation till or zero-till) do you use?
   ....
   ....

7. Do you apply farmyard manure to any of your land? YES/NO

8. If yes then please specify the amount of farmyard manure you apply.................kg/ha

9. Do you use inorganic fertilizers on your farm? YES/No

10. If yes then please specify the amount of inorganic fertilizer you apply ....kg/ha

11. If you manage livestock, can you please specify the number of each:

Type of livestock	**Numbers**
Total sheep	
Cattle 6-12 months	
Cattle 12 months-2 years	
Cattle over 2 years	
Dairy cows	
Fattening pigs	
Normal pigs	
Others (Please specify)	

12. Have you signed up to any payment scheme or agreement? **YES/NO**

13. If answer is **YES**, then please specify

....

....

SECTION B: Ranking Statements

Before carrying on with the choice cards, please provide answers to the following questions:

14. Do you think agriculture can have a role to play in reduction of the UK emissions?
....
....
....
....
....
....
......

15. Have you made any changes in your farm management activities to help reduce emissions?? **YES/NO**

16. If **YES,** what changes have you made?(Please specify)
....
....
....
....
....
....
....

17. How important do you think the following land management activities are for reducing greenhouse gas emissions and enhancing carbon storage? (Please encircle one number for each option)

Using appropriate amounts and timings of fertilizers

Unimportant	Of little importance	Moderately important	Important	Extremely important
1	2	3	4	5

Using reduced or conservation tillage

Unimportant	Of little importance	Moderately important	Important	Extremely important
1	2	3	4	5

Covering manure storage tanks (slurry tanks)

Unimportant	Of little importance	Moderately important	Important	Extremely important
1	2	3	4	5

Regulating the grazing period of livestock

Unimportant	Of little importance	Moderately important	Important	Extremely important
1	2	3	4	5

Improving the feed rates according to the animal needs

Unimportant	Of little importance	Moderately important	Important	Extremely important
1	2	3	4	5

Planting more trees on the farm

Unimportant	Of little importance	Moderately important	Important	Extremely important
1	2	3	4	5

Converting arable land to grassland

Unimportant	Of little importance	Moderately important	Important	Extremely important
1	2	3	4	5

SECTION C – Choice cards

Please read the explanation of the scenarios on the next page, only then move on to the choice cards presented and *choose **ONE** policy alternative (out of the three presented per choice card) best suited to you.*

EXPLANATION OF MITIGATION SCENARIO:

The mitigation scenario includes the development of anaerobic digestion plant, which can be both on-farm and a centralized (being shared with other local farms).

The basic purpose of developing anaerobic plants is not only to generate renewable energy which can be used for the farm or exported to the national grid for revenue generation (depending on the generating capacity) but it is beneficial for mitigating greenhouse gas emissions from agricultural sector as each **1kW** of electricity helps to reduce emissions from **2.5 cows** or **3 cars**.

The requirement of this scenario is to provide all the manure (assuming the livestock is housed throughout the year) produced from the livestock to the digestion plant for energy generation depending on the generator capacity of the digestion plant. In return you will be paid some compensation for participating in the scheme. The compensation will be provided to you in terms of £/ha for the complete farm size. You also have two options for the operation and management of the plant either to retain ownership and in this case you will enjoy the benefits yourself or to hand it over to a power-supply company and in that case you will have to share certain percentage of benefits with it.

Description of the attributes and their levels for this scheme is presented below:

Attributes	**Description**	**Levels**			
Generator capacity	The capacity of the plant to generate electricity kW/MW	20kW	50kW	1MW	2MW
Distance	The distance of the plant from the farm	<1km	~5km	10km	15km
Technical Assistance/training	whether they would like technical assistance/training provided with the program	Yes	No	-	-
Length of agreement	The minimum contract length they prefer	2 years	5 years	10 years	20 years
Plant ownership	Suitable option of receiving the benefits and ownership of the plant	Own the plant	Hand over to power-supply company	-	-
Compensation (£/ha)	Compensation payments	£10	£25	£50	£75

EXPLANATION OF SEQUESTRATION SCENARIO:

The sequestration scenario requires the changes in land use management activities to enhance carbon sequestration. This requires you to allocate a certain percentage of arable land to permanent grassland and for afforestation, changes in grazing time period, and changes in ploughing methods. In return you will be paid compensations in terms of per hectares payments according to your farm size.

The proposed changes can help to enhance the carbon storage (carbon sequestration) both in soil and vegetation. It has been calculated that conversion of **1 ha** of land (from arable land to permanent grassland/forest) can save **4.45 tCO_2/yr** which means that it saves emissions from approximately **2.2 cars**.

Description of the attributes and their levels for this scheme is as follows:

Attributes	Description	Levels			
Enrolment for permanent grassland	Area of land to enrol for conversion to grassland	10%	15%	30%	50%
Enrolment for afforestation	Area of land to enrol for afforestation	2%	5%	10%	15%
Grazing time periods	Preferable grazing time period	Only spring time grazing	Intensive grazing	-	-
Ploughing methods	Preferable ploughing method	Conservation till	Conventional till		
length of agreement	The minimum contract length they prefer	2 years	5 years	10 years	20 years
Compensation (£/ha)	compensation payments	£10	£25	£50	£75

Present the choice cards to the respondent here.

SECTION C: FOLLOW UP QUESTIONS

18. Which of these statements best describes the main reason for not choosing to participate in any of the programs that were offered to you in the choice cards? [CHOOSE ONE ANSWER ONLY]

The policy options presented were not important to me	1
The payments were not attractive enough	2
I do not have enough livestock at my farm	3
I do not want to sign up to an agreement	4
I already manage my farm in an environmentally responsible way	5
Some other reason (please specify)	6

19. Which of these statements best describe the main reason why you chose one of the two policy scenarios? [CHOOSE ONE ANSWER ONLY]

I would like to help to improve the climate regulation for my generation	1
I would like to improve the climate regulation service for our future generations	2
I would like to contribute towards nature conservation to the extend that I can afford	3
The program was a good business proposal	4
Some other reason (please specify)	5

SECTION D: SOCIO-ECONOMIC INFORMATION

Before finishing the survey please provide some answers about yourself to the following questions.

20. Can you please provide the address of your farm? (postcode at least)

....

....

....

1.	Gender (Male/Female)	
22.	Age (years)	
3.	What is the highest degree of education you have received? a) Primary school b) Secondary school c) College certificate d) Undergraduate degree e) Postgraduate degree	
4.	How many people are there in your household?	
5.	Is the income from the farm the main household income?	
6.	Can you please specify how much income is generated from the farm	
7.	Is there any other source of income?	
8.	If YES can you please specify the source and the amount?	

21. What do you think of this survey? [Please tick all that apply]

The questionnaire was interesting	
Difficult to understand	
Took a long time to think about the answers	
Informative	
Unrealistic	
Other (Please specify)	

THANK YOU VERY MUCH FOR YOUR TIME

APPENDIX B – Estimation of CE models without status quo model (No ASC)

This appendix provides the results of the CE models for which status quo was excluded.

Estimations for mitigation policy scheme

Model	**CLM**	**RPL**		**LCM (3 class)**		
Loglikelihood	**-1654.1**	**-1601.98**		**-1568**		
Pseudo-R^2	**0.15**	**0.26**		**0.27**		
AIC	**1.68**	**1.63**		**1.60**		
BIC	**1.69**	**1.64**		**1.66**		
Chi squared		**1133.3**		**1201.17**		
Degrees of Freedom		**11**		**20**		
Attributes	**Coefficient (SE)**	**Coefficient (SE)**	**Standard deviation (SE)**	**Segment 1**	**Segment 2**	**Segment 3**
Generator capacity	0.00006 (0.00004)	-0.000002 (0.00006)	0.0005*** (0.0001)	0.0002*** (0.00006)	-0.0009*** (0.0001)	0.0004 (0.0003)
Distance	-0.0411*** (0.0067)	-0.0408*** (0.0108)	0.1242*** (0.0138)	-0.0135 (0.0094)	-0.0378** (0.0136)	-0.6688*** (0.0848)
Technical assistance	0.3304*** (0.0713)	0.3599*** (0.0909)	0.5967** (0.1964)	0.3476*** (0.0967)	0.1193 (0.1521)	2.1596*** (0.3450)
Plant ownership	-0.6960*** (0.0781)	-0.8030*** (0.0989)	0.5659** (0.2039)	-0.5825*** (0.1094)	-0.8456*** (0.1521)	-2.4759*** (0.3705)
Length of agreement	-0.0119* (0.0050)	-0.0185* (0.0071)	0.0637*** (0.0097)	0.0047 (0.0073)	-0.1247*** (0.0130)	0.1223*** (0.0268)
Compensation	0.0358*** (0.0014)	0.0477*** (0.0024)		0.0392*** (0.0022)	0.0569*** (0.0028)	0.0423*** (0.0076)
Percentage				65%	25%	10%

Estimations for sequestration policy scheme

Model	CLM	RPL		LCM (2 class)	
Loglikelihood	-649.59	-618.21		-625.88	
Pseudo-R^2	0.13	0.18		0.17	
AIC	1.90	1.81		1.85	
BIC	1.93	1.87		1.93	
Chi squared		279.66		264.32	
Degrees of Freedom		9		13	
Attributes	Coefficients (SE)	Coefficients (SE)	Standard deviation (SE)	Segment 1	Segment 2
Conversion to permanent grassland	-0.4284*** (0.0043)	-0.0534*** (0.0065)	0.03207*** (0.0068)	-0.2054*** (0.0494)	-0.0302*** (0.0033)
Conversion for afforestation	0.0053 (0.0086)	0.0021 (0.0102)	0.7475** (0.2775)	-0.0177 (0.0398)	0.0058 (0.0082)
Grazing time period	0.1761 (0.1187)	0.1685 (0.1587)	1.6316*** (0.2416)	1.4717* (0.6269)	0.0675 (0.0923)
Ploughing methods	-0.5209*** (0.1216)	-0.6832** (0.2145)		1.8265* (0.0325)	-1.0310*** (0.09239)
Length of agreement	0.0164* (0.0086)	0.0247* (0.0106)		0.0322 (0.0325)	0.0156* (0.0075)
Compensation	0.0269*** (0.0024)	0.0348*** (0.0032)		0.0478*** (0.0105)	0.0294*** (0.0022)
Percentage				25%	75%

APPENDIX C- Consistency of responses for both scenarios

For mitigation policy scheme:

A dummy 'PS' was introduced into the model which is 1 if the respondent 'participated in both mitigation and sequestration schemes' and 0 if the respondent 'participated in mitigation scheme only'. Only three of the attributes were significant revealing that the respondents who participated in both schemes show a different behaviour towards these attributes only; showing a significant preference towards low generator capacities which means that they prefer smaller AD plants, a preference towards longer length of agreements, and are willing to participate in schemes for low compensation payments.

Model	**CLM**	
Loglikelihood	-1605.89	
Pseudo-R^2	0.18	
AIC	1.63	
BIC	1.64	
Attributes	**Coefficient**	**Standard error**
GCAP	0.00007	-0.00004
DIST	-0.0700	0.0075***
TECH	0.1230	0.0755
OWN	-0.9055	0.0819***
LOA	-0.0388	0.0062***
COMP	0.0310	0.0017***
ASC	-1.1952	0.1368***
PS*GCAP	-0.0003	0.0001**
PS*LOA	0.0289	0.0118*
PS*COMP	-0.0053	0.0029*

For sequestration policy scheme:

A dummy 'PM' was included in the model to analyse the change in the behaviour of the respondents who participated in both sequestration and mitigation scheme. PM had a value of 1 for the respondents who participated in both the schemes while 0 for the respondents who participated in sequestration scheme only. The results reveal that respondents who participate in both schemes show a significant aversion towards longer contracts. Hence, revealing that respondents who participate only in sequestration scheme show a positive preference towards longer contract lengths. This result helped to identify farms which can easily be attracted towards longer contracts making sequestration policies more effective, since carbon sequestration both in soil and vegetation requires longer time period.

Model	**CLM**	
Loglikelihood	-601.92	
Pseudo-R^2	0.19	
AIC	1.76	
BIC	1.82	
Attributes	**Coefficient**	**Standard error**
PGRASS	-0.0659	0.0050***
AFFOR	-0.0270	0.0132*
GRAZ	-0.3145	0.1324*
PLOUGH	-0.9867	0.1399***
LOA	0.00514	0.0133
COMP	0.0150	0.0027***
ASC	-2.4973	2.6619***
PM*LOA	-0.0447	0.0148**

APPENDIX D – Choice cards

CHOICE CARDS FOR MITIGATION SCENARIO

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	20kW	20kW	I do not want to participate
Distance	<1km	<1km	
Length of agreement	2 yrs	2 yrs	
Technical assistance/ Training	Yes	Yes	
Plant ownership	Own the plant	Own the plant	
Compensation (£/ha)	£10	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	1MW	2MW	I do not want to participate
Distance	10km	~5km	
Length of agreement	5 yrs	10 yrs	
Technical assistance/ Training	No	Yes	
Plant ownership	Handover to power-supply company	Handover to power-supply company	
Compensation (£/ha)	£50	£50	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	1MW	2MW	I do not want to participate
Distance	<1km	15km	
Length of agreement	10 yrs	2 yrs	
Technical assistance/ Training	Yes	No	
Plant ownership	Handover to power-supply company	Ownership of plant	
Compensation (£/ha)	£25	£50	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	2MW	1MW	I do not want to participate
Distance	15km	15km	
Length of agreement	10 yrs	10 yrs	
Technical assistance/ Training	Yes	No	
Plant ownership	Ownership of plant	Handover to power-supply company	
Compensation (£/ha)	£10	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	50kW	50kW	I do not want to participate
Distance	~5km	15km	
Length of agreement	2 yrs	2 yrs	
Technical assistance/ Training	No	Yes	
Plant ownership	Handover to power-supply company	Handover to power-supply company	
Compensation (£/ha)	£50	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	2MW	20kW	I do not want to participate
Distance	~5km	<1km	
Length of agreement	5 yrs	10 yrs	
Technical assistance/ Training	No	No	
Plant ownership	Own the plant	Own the plant	
Compensation (£/ha)	£25	£50	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	1MW	20kW	I do not want to participate
Distance	~5km	<1km	
Length of agreement	20 yrs	5 yrs	
Technical assistance/ Training	Yes	No	
Plant ownership	Handover to power-supply company	Handover to power-supply company	
Compensation (£/ha)	£50	£75	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	20kW	2MW	I do not want to participate
Distance	15km	10km	
Length of agreement	10 yrs	5 yrs	
Technical assistance/ Training	No	Yes	
Plant ownership	Own the plant	Own the plant	
Compensation (£/ha)	£75	£75	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	20kW	2MW	I do not want to participate
Distance	15km	~5km	
Length of agreement	5 yrs	20 yrs	
Technical assistance/ Training	Yes	Yes	
Plant ownership	Handover to power-supply company	Own the plant	
Compensation (£/ha)	£25	£25	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	20kW	50kW	I do not want to participate
Distance	15km	10km	
Length of agreement	20 yrs	20 yrs	
Technical assistance/ Training	No	No	
Plant ownership	Handover to power-supply company	Own the plant	
Compensation (£/ha)	£10	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	1MW	1MW	I do not want to participate
Distance	15km	<1km	
Length of agreement	2 yrs	5 yrs	
Technical assistance/ Training	No	No	
Plant ownership	Own the plant	Handover to power-supply company	
Compensation (£/ha)	£75	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	20kW	20kW	I do not want to participate
Distance	~5km	15km	
Length of agreement	20 yrs	20 yrs	
Technical assistance/ Training	Yes	Yes	
Plant ownership	Own the plant	Handover to power-supply company	
Compensation (£/ha)	£75	£25	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	20kW	20kW	I do not want to participate
Distance	10km	10km	
Length of agreement	20 yrs	5 yrs	
Technical assistance/ Training	Yes	Yes	
Plant ownership	Own the plant	Handover to power-supply company	
Compensation (£/ha)	£10	£25	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	2MW	20kW	I do not want to participate
Distance	10km	10km	
Length of agreement	2 yrs	10 yrs	
Technical assistance/ Training	No	No	
Plant ownership	Handover to power-supply company	Own the plant	
Compensation (£/ha)	£75	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	50kW	1MW	
Distance	<1km	~5km	
Length of agreement	20 yrs	2 yrs	I do not want to participate
Technical assistance/ Training	No	No	
Plant ownership	Own the plant	Handover to power-supply company	
Compensation (£/ha)	£75	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	50kW	1MW	
Distance	<1km	10km	
Length of agreement	2 yrs	5 yrs	I do not want to participate
Technical assistance/ Training	Yes	No	
Plant ownership	Handover to power-supply company	Own the plant	
Compensation (£/ha)	£10	£75	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	2MW	50kW	I do not want to participate
Distance	10km	<1km	
Length of agreement	5 yrs	5 yrs	
Technical assistance/ Training	Yes	Yes	
Plant ownership	Own the plant	Own the plant	
Compensation (£/ha)	£50	£25	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	2MW	2MW	I do not want to participate
Distance	<1km	~5km	
Length of agreement	10 yrs	20 yrs	
Technical assistance/ Training	No	Yes	
Plant ownership	Handover to power-supply company	Handover to power-supply company	
Compensation (£/ha)	£25	£75	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	**2MW**	**1MW**	**I do not want to participate**
Distance	**<1km**	**<1km**	
Length of agreement	**20 yrs**	**20 yrs**	
Technical assistance/ Training	**Yes**	**Yes**	
Plant ownership	**Handover to power-supply company**	**Own the plant**	
Compensation (£/ha)	**£50**	**£10**	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	**50kW**	**50kW**	**I do not want to participate**
Distance	**10km**	**10km**	
Length of agreement	**10 yrs**	**5 yrs**	
Technical assistance/ Training	**Yes**	**No**	
Plant ownership	**Handover to power-supply company**	**Handover to power-supply company**	
Compensation (£/ha)	**£75**	**£50**	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	50kW	1MW	I do not want to participate
Distance	10km	15km	
Length of agreement	5 yrs	5 yrs	
Technical assistance/ Training	No	Yes	
Plant ownership	Own the plant	Own the plant	
Compensation (£/ha)	£25	£50	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	2MW	20kW	I do not want to participate
Distance	10km	~5km	
Length of agreement	10 yrs	20 yrs	
Technical assistance/ Training	No	No	
Plant ownership	Own the plant	Own the plant	
Compensation (£/ha)	£10	£75	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	50kW	2MW	I do not want to participate
Distance	~5km	15km	
Length of agreement	2 yrs	20 yrs	
Technical assistance/ Training	Yes	No	
Plant ownership	Own the plant	Handover to company	
Compensation (£/ha)	£50	£25	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	2MW	50kW	I do not want to participate
Distance	~5km	10km	
Length of agreement	5 yrs	5 yrs	
Technical assistance/ Training	No	Yes	
Plant ownership	Handover to power-supply company	Handover to power-supply company	
Compensation (£/ha)	£25	£25	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	20kW	2MW	I do not want to participate
Distance	10km	<1km	
Length of agreement	20 yrs	2 yrs	
Technical assistance/ Training	No	No	
Plant ownership	Own the plant	Handover to power-supply company	
Compensation (£/ha)	£10	£25	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	1MW	20kW	I do not want to participate
Distance	10km	10km	
Length of agreement	2 yrs	10 yrs	
Technical assistance/ Training	Yes	Yes	
Plant ownership	Own the plant	Handover to power-supply company	
Compensation (£/ha)	£75	£75	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	20kW	20kW	I do not want to participate
Distance	<1km	15km	
Length of agreement	20 yrs	10 yrs	
Technical assistance/ Training	No	No	
Plant ownership	Handover to power-supply company	Own the plant	
Compensation (£/ha)	£75	£25	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	2MW	1MW	I do not want to participate
Distance	~5km	10km	
Length of agreement	20 yrs	2 yrs	
Technical assistance/ Training	No	Yes	
Plant ownership	Own the plant	Own the plant	
Compensation (£/ha)	£50	£50	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	50 kW	2 MW	I do not want to participate
Distance	15km	<1 km	
Length of agreement	10 yrs	10 yrs	
Technical assistance/ Training	Yes	Yes	
Plant ownership	Handover to power-supply company	Own the plant	
Compensation (£/ha)	£75	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	50 kW	20 kW	I do not want to participate
Distance	15km	~5 km	
Length of agreement	5 yrs	2 yrs	
Technical assistance/ Training	Yes	No	
Plant ownership	Handover to power-supply company	Handover to power-supply company	
Compensation (£/ha)	£25	£50	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	1 MW	20 kW	I do not want to participate
Distance	10km	15 km	
Length of agreement	10 yrs	2 yrs	
Technical assistance/ Training	No	Yes	
Plant ownership	Handover to power-supply company	Handover to power-supply company	
Compensation (£/ha)	£10	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	20 kW	50 kW	I do not want to participate
Distance	<1km	~5 km	
Length of agreement	2 yrs	20 yrs	
Technical assistance/ Training	No	No	
Plant ownership	Own the plant	Own the plant	
Compensation (£/ha)	£50	£50	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	1 MW	2 MW	I do not want to participate
Distance	<1km	10 km	
Length of agreement	5 yrs	20 yrs	
Technical assistance/ Training	Yes	No	
Plant ownership	Own the plant	Handover to power-supply company	
Compensation (£/ha)	£25	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	20kW	1 MW	I do not want to participate
Distance	~5km	<1 km	
Length of agreement	2 yrs	10 yrs	
Technical assistance/ Training	No	Yes	
Plant ownership	Handover to power-supply company	Handover to power-supply company	
Compensation (£/ha)	£10	£75	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	1 MW	2 MW	I do not want to participate
Distance	15km	15 km	
Length of agreement	5 yrs	2 yrs	
Technical assistance/ Training	Yes	No	
Plant ownership	Handover to power-supply company	Own the plant	
Compensation (£/ha)	£50	£75	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Generator capacity	1 MW	2 MW	I do not want to participate
Distance	15km	15 km	
Length of agreement	5 yrs	2 yrs	
Technical assistance/ Training	Yes	No	
Plant ownership	Handover to power-supply company	Own the plant	
Compensation (£/ha)	£50	£75	
I would choose to participate in	☐	☐	☐

CHOICE CARD FOR SEQUESTRATION SCENARIO

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	10%	10%	I do not want to participate
Area of land for reforestation	2%	2%	
Grazing time periods	Only spring grazing	Only spring grazing	
Ploughing methods	Conservation till	Conservation till	
Length of agreement	2 years	2 years	
Compensation (£/ha)	£10	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	30%	50%	I do not want to participate
Area of land for reforestation	10%	5%	
Grazing time periods	Intensive grazing	Only spring grazing	
Ploughing methods	Conventional till	Conventional till	
Length of agreement	5 years	10 years	
Compensation (£/ha)	£50	£50	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	**30%**	**50%**	**I do not want to participate**
Area of land for reforestation	**2%**	**15%**	
Grazing time periods	**Only spring grazing**	**Intensive grazing**	
Ploughing methods	**Conventional till**	**Conservation till**	
Length of agreement	**10 years**	**2 years**	
Compensation (£/ha)	**£25**	**£50**	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	**50%**	**50%**	**I do not want to participate**
Area of land for reforestation	**15%**	**15%**	
Grazing time periods	**Only spring grazing**	**Intensive grazing**	
Ploughing methods	**Conservation till**	**Conventional till**	
Length of agreement	**10 years**	**10 years**	
Compensation (£/ha)	**£10**	**£10**	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	15%	15%	I do not want to participate
Area of land for reforestation	5%	15%	
Grazing time periods	Intensive grazing	Only spring grazing	
Ploughing methods	Conventional till	Conventional till	
Length of agreement	2 years	2 years	
Compensation (£/ha)	£50	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	50%	15%	I do not want to participate
Area of land for reforestation	5%	2%	
Grazing time periods	Intensive grazing	Intensive grazing	
Ploughing methods	Conventional till	Conventional till	
Length of agreement	5 years	10 years	
Compensation (£/ha)	£25	£50	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	**30%**	**10%**	**I do not want to participate**
Area of land for reforestation	**5%**	**2%**	
Grazing time periods	**Only spring grazing**	**Intensive grazing**	
Ploughing methods	**Conventional till**	**Conventional till**	
Length of agreement	**20 years**	**5 years**	
Compensation (£/ha)	**£50**	**£75**	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	**10%**	**50%**	**I do not want to participate**
Area of land for reforestation	**15%**	**10%**	
Grazing time periods	**Intensive grazing**	**Only spring grazing**	
Ploughing methods	**Conservation till**	**Conservation till**	
Length of agreement	**10 years**	**5 years**	
Compensation (£/ha)	**£75**	**£75**	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	10%	30%	I do not want to participate
Area of land for reforestation	15%	5%	
Grazing time periods	Only spring grazing	Only spring grazing	
Ploughing methods	Conventional till	Conservation till	
Length of agreement	5 years	20 years	
Compensation (£/ha)	£25	£25	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	10%	15%	I do not want to participate
Area of land for reforestation	15%	10%	
Grazing time periods	Intensive grazing	Intensive grazing	
Ploughing methods	Conventional till	Conservation till	
Length of agreement	20 years	20 years	
Compensation (£/ha)	£10	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	30%	30%	I do not want to participate
Area of land for reforestation	15%	2%	
Grazing time periods	Intensive grazing	Intensive grazing	
Ploughing methods	Conservation till	Conventional till	
Length of agreement	2 years	5 years	
Compensation (£/ha)	£75	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	10%	10%	I do not want to participate
Area of land for reforestation	5%	15%	
Grazing time periods	Only spring grazing	Only spring grazing	
Ploughing methods	Conservation till	Conventional till	
Length of agreement	20 years	20 years	
Compensation (£/ha)	£75	£50	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	15%	15%	I do not want to participate
Area of land for reforestation	10%	10%	
Grazing time periods	Only spring grazing	Only spring grazing	
Ploughing methods	Conservation till	Conventional till	
Length of agreement	20 years	10 years	
Compensation (£/ha)	£10	£75	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	50%	10%	I do not want to participate
Area of land for reforestation	10%	10%	
Grazing time periods	Intensive grazing	Intensive grazing	
Ploughing methods	Conventional till	Conservation till	
Length of agreement	2 years	10 years	
Compensation (£/ha)	£75	£25	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	15%	30%	I do not want to participate
Area of land for reforestation	2%	5%	
Grazing time periods	Intensive grazing	Intensive grazing	
Ploughing methods	Conservation till	Conventional till	
Length of agreement	20 years	2 years	
Compensation (£/ha)	£75	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	15%	30%	I do not want to participate
Area of land for reforestation	2%	10%	
Grazing time periods	Only spring grazing	Intensive grazing	
Ploughing methods	Conventional till	Conservation till	
Length of agreement	2 years	5 years	
Compensation (£/ha)	£10	£75	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	50%	15%	I do not want to participate
Area of land for reforestation	10%	5%	
Grazing time periods	Only spring grazing	Only spring grazing	
Ploughing methods	Conservation till	Conservation till	
Length of agreement	5 years	5 years	
Compensation (£/ha)	£50	£25	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	50%	50%	I do not want to participate
Area of land for reforestation	2%	5%	
Grazing time periods	Intensive grazing	Only spring grazing	
Ploughing methods	Conventional till	Conventional till	
Length of agreement	10 years	20 years	
Compensation (£/ha)	£25	£75	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	50%	30%	I do not want to participate
Area of land for reforestation	2%	2%	
Grazing time periods	Only spring grazing	Only spring grazing	
Ploughing methods	Conventional till	Conservation till	
Length of agreement	20 years	20 years	
Compensation (£/ha)	£50	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	15%	15%	I do not want to participate
Area of land for reforestation	10%	2%	
Grazing time periods	Intensive grazing	Only spring grazing	
Ploughing methods	Conventional till	Conventional till	
Length of agreement	10 years	5 years	
Compensation (£/ha)	£75	£50	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	15%	30%	I do not want to participate
Area of land for reforestation	5%	15%	
Grazing time periods	Intensive grazing	Only spring grazing	
Ploughing methods	Conservation till	Conservation till	
Length of agreement	5 years	5 years	
Compensation (£/ha)	£25	£50	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	50%	10%	I do not want to participate
Area of land for reforestation	15%	5%	
Grazing time periods	Intensive grazing	Intensive grazing	
Ploughing methods	Conservation till	Conservation till	
Length of agreement	10 years	5 years	
Compensation (£/ha)	£10	£75	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	15%	50%	I do not want to participate
Area of land for reforestation	5%	15%	
Grazing time periods	Only spring grazing	Intensive grazing	
Ploughing methods	Conservation till	Conventional till	
Length of agreement	2 years	20 years	
Compensation (£/ha)	£50	£25	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	50%	15%	I do not want to participate
Area of land for reforestation	5%	10%	
Grazing time periods	Intensive grazing	Only spring grazing	
Ploughing methods	Conventional till	Conventional till	
Length of agreement	5 years	5 years	
Compensation (£/ha)	£25	£25	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	10%	50%	I do not want to participate
Area of land for reforestation	10%	2%	
Grazing time periods	Intensive grazing	Intensive grazing	
Ploughing methods	Conservation till	Conventional till	
Length of agreement	20 years	2 years	
Compensation (£/ha)	£10	£25	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	30%	10%	I do not want to participate
Area of land for reforestation	10%	10%	
Grazing time periods	Only spring grazing	Only spring grazing	
Ploughing methods	Conservation till	Conventional till	
Length of agreement	2 years	10 years	
Compensation (£/ha)	£75	£75	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	10%	10%	I do not want to participate
Area of land for reforestation	2%	15%	
Grazing time periods	Intensive grazing	Intensive grazing	
Ploughing methods	Conventional till	Conservation till	
Length of agreement	20 years	10 years	
Compensation (£/ha)	£75	£25	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	50%	30%	I do not want to participate
Area of land for reforestation	5%	10%	
Grazing time periods	Intensive grazing	Only spring grazing	
Ploughing methods	Conservation till	Conservation till	
Length of agreement	20 years	2 years	
Compensation (£/ha)	£50	£50	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	15%	50%	I do not want to participate
Area of land for reforestation	15%	2%	
Grazing time periods	Only spring grazing	Only spring grazing	
Ploughing methods	Conventional till	Conservation till	
Length of agreement	10 years	10 years	
Compensation (£/ha)	£75	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	15%	10%	I do not want to participate
Area of land for reforestation	15%	5%	
Grazing time periods	Only spring grazing	Intensive grazing	
Ploughing methods	Conventional till	Conventional till	
Length of agreement	5 years	2 years	
Compensation (£/ha)	£25	£50	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	30%	10%	I do not want to participate
Area of land for reforestation	10%	15%	
Grazing time periods	Intensive grazing	Only spring grazing	
Ploughing methods	Conventional till	Conventional till	
Length of agreement	10 years	5 years	
Compensation (£/ha)	£10	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	10%	15%	I do not want to participate
Area of land for reforestation	2%	5%	
Grazing time periods	Intensive grazing	Intensive grazing	
Ploughing methods	Conservation till	Conservation till	
Length of agreement	2 years	20 years	
Compensation (£/ha)	£50	£50	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	30%	50%	I do not want to participate
Area of land for reforestation	2%	10%	
Grazing time periods	Only spring grazing	Intensive grazing	
Ploughing methods	Conservation till	Conventional till	
Length of agreement	5 years	20 years	
Compensation (£/ha)	£25	£10	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	10%	30%	I do not want to participate
Area of land for reforestation	5%	2%	
Grazing time periods	Intensive grazing	Only spring grazing	
Ploughing methods	Conservation till	Conservation till	
Length of agreement	2 years	10 years	
Compensation (£/ha)	£10	£75	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	**30%**	**50%**	**I do not want to participate**
Area of land for reforestation	**15%**	**15%**	
Grazing time periods	**Only spring grazing**	**Intensive grazing**	
Ploughing methods	**Conventional till**	**Conservation till**	
Length of agreement	**5 years**	**2 years**	
Compensation (£/ha)	**£25**	**£75**	
I would choose to participate in	☐	☐	☐

Attributes	Alt_1	Alt_2	Alt_3
Area of land converted to permanent grassland	**30%**	**15%**	**I do not want to participate**
Area of land for reforestation	**50%**	**5%**	
Grazing time periods	**Only spring grazing**	**Only spring grazing**	
Ploughing methods	**Conservation till**	**Conservation till**	
Length of agreement	**10 years**	**2 years**	
Compensation (£/ha)	**£25**	**£25**	
I would choose to participate in	☐	☐	☐