The prospects for increasing UK production of feedstocks for bioenergy

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Abstract

Bioenergy could play an important role in reducing UK greenhouse gas emissions to net zero by 2050, but biomass production and use will have to increase significantly. This research explores what potential there is for increasing biomass production, and how that increase could be delivered, using Yorkshire and Humberside (Y&H) as a case study. A mixed methods approach was used combining a biomass assessment, stakeholder interviews and policy analysis. Comparing the Y&H biomass potential with the regional bioenergy generation, identified biomass types with potential for greater production or use. Semi-structured interviews held with farmers, landowners, foresters, and industry experts were analysed using a framework based on Rogers' Theory of Diffusion of Innovations. Policies to promote woodland creation and perennial energy crop (PEC) cultivation, identified from literature and the stakeholder interviews, were assessed using a policy Delphi, to produce recommendations for government action.

Energy crops have the most potential to increase biomass production in the UK, and annual energy crops (e.g. maize and grass) are popular with farmers, but cultivation of the PECs miscanthus and short rotation coppice willow has stagnated because of limited markets, competitive cereal prices, the length of commitment required, and cultural barriers. Sustainably managed woodlands can deliver carbon sequestration, and woodfuel, but barriers to creation include the permanence of planting, loss of annual farming income, expense of planting and maintenance, and cultural divisions between forestry and farming. Although a considerable volume of poultry litter is produced in the UK, bioenergy use is constrained by the competing demand for organic fertiliser, and the high capital cost of on-farm combustion.

Significant policy action will be needed in the UK to increase biomass supply. Demand side incentives could create a market for PEC biomass, support attractive long-term contracts, and stimulate growth of the full supply chain, while short term planting support could also be effective to drive adoption. Woodland creation could be driven by rewards for delivering carbon sequestration (a public good), and attractive grants to cover establishment costs and replace lost income. More information and education could overcome the traditional divide between farming and forestry. The new Environmental Land Management scheme in England (and corresponding schemes in the rest of the UK) will also be vital in delivering the landscape scale changes of land use needed to meet the UK's net zero targets, including the changes required to increase the domestic supply of biomass for bioenergy.

List of abbreviations

AD	Anaerobic digestion
ADBA	Anaerobic Digestion and Bioresources Association
AONB	Area of outstanding natural beauty
BECCS	Bioenergy with carbon capture and storage
BEIS	Department for Business, Energy & Industrial Strategy
CCC	Climate Change Committee (formerly Committee on Climate Change)
CCS	Carbon capture and storage
CfD	Contracts for Difference
CHP	Combined heat and power generation
CLA	Country Land and Business Association
Confor	Confederation of Forest Industries
COP26	The 26th United Nations Climate Change Conference of the Parties (2021)
CSR	Corporate social responsibility
DECC	Department of Energy & Climate Change (superseded by BEIS in July 2016)
DEFRA	Department for Environment, Food & Rural Affairs
DfT	Department for Transport
DM	Dry matter
DOI	Diffusion of Innovations
EA	Environment Agency
ECS	Energy Crops Scheme
ECS2	Second phase of the Energy Crops Scheme
EfW	Energy from waste
EIA	Environmental impact assessment
ELM	Environmental Land Management
ELMS	Environmental Land Management Scheme
ES	Ecosystems services
EU	European Union
EU ETS	EU Emissions Trading Scheme
FAO	Food and Agriculture Organisation of the United Nations
FC	Forestry Commission
FIT	Feed in tariff
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
LCA	Life cycle assessment

LCC	Leeds City Council
LCR	Leeds City Region
MHCLG	Ministry of Housing, Communities & Local Government
MSW	Municipal solid waste
NNFCC	National Non-Food Crop Centre
NE	Natural England
NFU	National Farmers Union
NGO	Non-governmental organisation
NI	Northern Ireland
NUTS	Nomenclature of Territorial Units
NVZ	Nitrate Vulnerable Zone
odt	Oven dried tonnes
OFGEM	Office of Gas and Electricity Markets
OSR	Oil seed rape
PEC	Perennial energy crop
PES	Payments for ecosystem (or environmental) services
RHI	Renewable Heat Incentive
RO	Renewables Obligation
RPA	Rural Payments Agency
SRC	Short rotation coppice (usually either willow or poplar)
SRF	Short rotation forestry (also known as energy forestry)
SSSI	Site of Special Scientific Interest
TRA	Theory of Reasoned Action
toe	Tonnes of oil equivalent
TPB	Theory of Planned Behaviour
UK	United Kingdom of Great Britain and Northern Ireland
UKFS	United Kingdom Forest Standard
UK ETS	UK Emissions Trading Scheme
UTAUT	Unified theory of acceptance and use of technology
WCG	Woodland Carbon Guarantee
WRAP	Waste and Resource Action Programme (UK waste reduction charity)
WT	Woodland Trust
Y&H	Yorkshire and Humberside

Table of contents

List of tables

List of figures

List of boxes

Chapter 1 Introduction

Bioenergy met 8.1 % of the UK energy demand, and contributed two thirds of all UK renewable energy in 2019 (BEIS, 2020b, p106), using both imported and domestically produced biomass. Many estimates have been made of the contribution that domestic biomass could make by 2050, and most are in the range from 4 % to 11 % of UK energy demand (Slade et al., 2010; Ricardo Energy & Environment, 2017) but a share of up to 44 % has also been predicted (Welfle et al., 2014).

As the urgency of climate change has been recognised, targets for reducing greenhouse gas (GHG) emissions have become increasingly ambitious, culminating in the target to reduce GHG emissions to net zero by 2050, adopted by the UK in 2019 (CCC, 2019). Bioenergy is no longer viewed only as a way of reducing GHG emissions by displacing fossil fuels. It is now valued for its potential, when deployed with carbon capture and storage (CCS), to deliver the negative emissions needed to compensate for sectors which cannot be fully decarbonised (CCC, 2020e). Significant increases in the supply of biomass may be needed in the UK if the net zero targets are to be met (CCC, 2020c).

1.1 Bioenergy in the UK

Traditional bioenergy, predominantly from the combustion of woodfuel and agricultural residues, was the main source of energy worldwide until the early 19th century, and it remains the main source in much of the developing world (Rosillo-Calle et al., 2007). In the UK and rest of the industrialised world coal, then oil and gas, took over as the main fuel sources in the 19th and 20th centuries. It was not until the oil crisis of the 1970s that bioenergy was considered as a replacement for fossil fuels, to deliver energy security and to lower costs (Slade et al., 2017). Climate change became a global priority in the late 1980s, and the IPCC (Intergovernmental Panel on Climate Change) was formed in 1988 (IPCC, 2021). Bioenergy was seen as a low carbon alternative to fossil fuels, and GHG reduction became the prime driver for increasing bioenergy generation (Slade et al., 2017). The EU Renewable Energy Directive (Directive 2009/28/EC, 2009) committed the EU to sourcing 20 % of final energy consumption from renewable sources by 2020, with a UK target of 15 % by 2020. Bioenergy for electricity, heat and transport were all part of the UK response to the targets (BEIS, 2011). By 2019 the UK was meeting 12.3 % of energy demand from renewable sources: 35 % of electricity generation, 7.9 % of heat and 8.8 % of transport fuels (BEIS, 2020b).

Figure 1.1 shows the contribution of each type of biomass to the generation of electricity and heat in the UK in 2019. It shows that plant biomass (which includes wood pellets) is the largest source of fuel, and currently 59 % is imported (BEIS, 2020b). The pellets imported predominantly from the USA and Canada are used mainly by Drax and Lynemouth power stations (OFGEM, 2020c; OFGEM, 2021), but also by smaller generators and in domestic and smaller commercial pellet heating boilers (Harrison, 2020). The future supply of imported biomass will depend on the global supply and demand, and the UK may not be able to rely on imports at this scale in future (Ricardo Energy & Environment, 2020; CCC, 2018a; Ricardo Energy & Environment, 2017). Domestic biomass may be needed to provide security of supply. Miscanthus, willow and straw are also combusted in power stations (OFGEM, 2020c), and virgin woodfuel makes a significant contribution to heat generation.

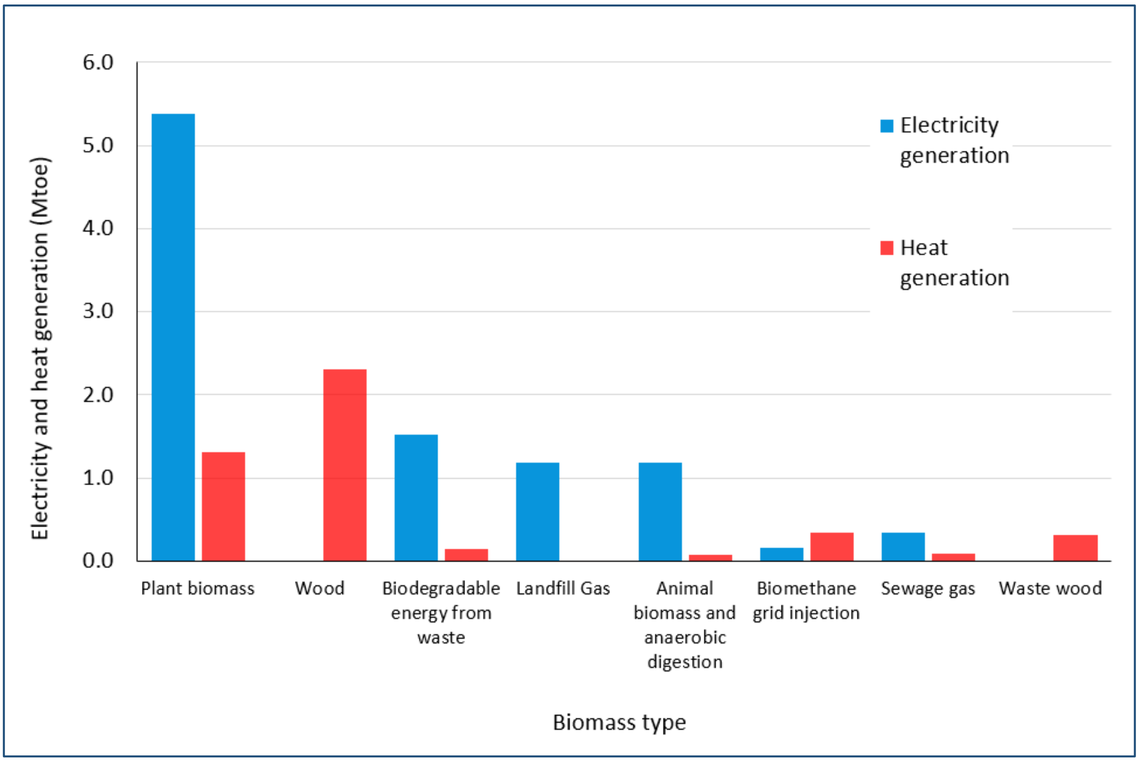

Figure 1.1 UK generation of electricity and heat by biomass type in 2019
Generation data from BEIS (2020a), biomethane injection BEIS (2020b, p118), and assumed split of biomethane end use between electricity and heat derived from BEIS (2020b, p65).

Energy from waste (EfW) plants were built to process waste formerly sent to landfill, as a part of the EU drive to reduce methane emissions from biogenic waste (Directive 1999/31/EC, 1999). As the contribution from EfW has increased, the landfill gas supply has declined (BEIS, 2017a). Animal biomass and chicken litter is still combusted in the power stations built in the 1990s (Kelleher et al., 2002; BEIS, 2017a; Melton Renewable Energy UK Limited, 2016) and litter and manures are feedstocks for AD plants. By spring 2020 there were 672 anaerobic digestion (AD) plants in the UK, including 108 plants injecting biomethane into the gas grid (ADBA, 2020). The different types of biomass are discussed in more detail in section 2.2.

1.2 Crops grown for energy in the UK

Figure 1.2 shows the areas of bioenergy crops grown in the UK from 2008 to 2019. It shows that since 2014, when separate data for energy maize was first available, cultivation has increased and it is now the most widely grown UK energy crop. Wheat production for biofuels has declined in the last three years and oil seed rape (OSR) has not been grown for energy since 2014. Miscanthus and short rotation coppice (mainly willow) cultivation has not changed significantly since 2008.

1.3 Bioenergy and the UK net zero GHG emissions targets

In June 2019 the UK became the first country to commit, in legislation, to reducing national greenhouse gas (GHG) emissions to net zero by 2050 (Prime Minister's Office, 2019). This target was recommended by the Climate Change Committee (CCC) (BEIS and Skidmore, 2019), the independent statutory body established under the *Climate Change Act (Climate Change Act 2008)* to advise the UK and devolved governments on GHG emissions reduction, and adaptation to climate change (HM Government et al., 2010). The target of net zero by 2050 exceeds the reductions needed globally to limit the expected rise in global average temperature to well below 2 °C, and if adopted worldwide, it would deliver a greater than 50 % chance of limiting the temperature increase to 1.5°C (CCC, 2019). The *net zero* target means that any remaining emissions from sectors which are hard to decarbonise, such as agriculture and aviation, would have to be balanced by carbon sequestration from, for example, growing trees or using bioenergy with carbon capture and storage (BECCS) (BEIS and Skidmore, 2019).

The CCC has proposed ways in which the net zero target could be met in the UK, building on progress already made in decarbonising electricity generation, developing electric vehicles, and reducing the volume of biogenic waste sent to landfill. Measures include: reducing the demand for carbon intensive activities such as flying, electrifying transport and heating, further decarbonising electricity generation, and developing a hydrogen industry (CCC, 2019). It also recommends large scale BECCS using perennial energy crops (PECs) and woodfuel as feedstocks, significant woodland creation, peatland restoration, and reducing the number of ruminant livestock (mainly cattle and sheep), all of which require significant changes to land use in the UK (CCC, 2020a). The IPCC (IPCC, 2018; Rogelj et al., 2018) also includes BECCS in its pathways for limiting climate change. The scenarios constructed by the CCC to meet net zero include the *Further Ambition* scenario which increases the area of woodland cover in the UK

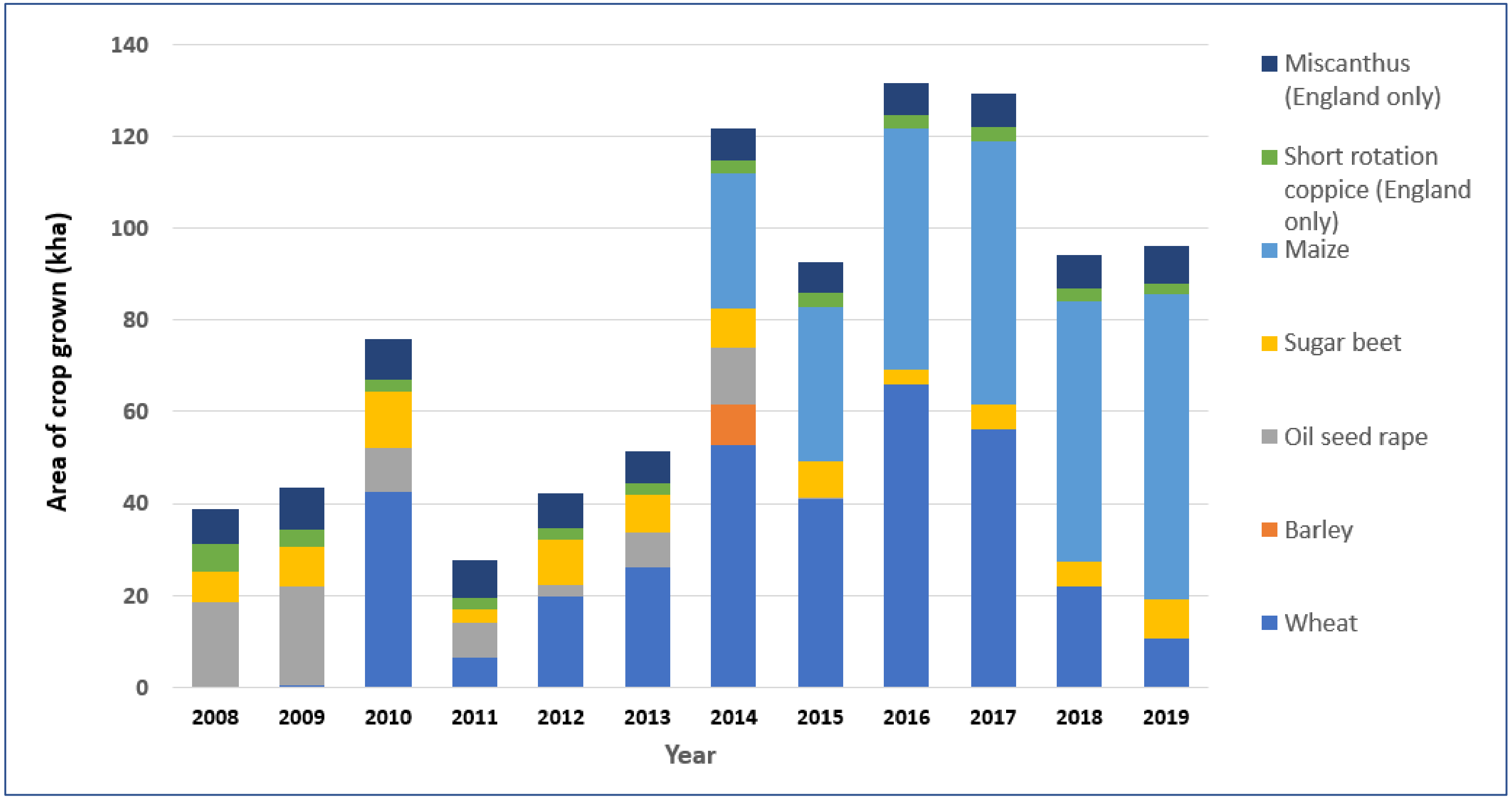

Figure 1.2 Areas of crops grown for bioenergy in the UK from 2008 to 2019
Data from DEFRA (2020a, Table A).

from 13 % to 17 % by 2050, and increases the area of PECs from 10 kha to 700 kha by 2050 (CCC, 2020a). Other scenarios which model delivering net zero emissions require even greater planting of trees or PECs, e.g. the ESC *Clockwork* and *Patchwork* scenarios (Energy Systems Catapult, 2020) and the CCC *Speculative* scenario (CCC, 2020a).

When the *UK Climate Change Act* (Climate Change Act 2008) was passed it included the requirement for carbon budgets (targets for GHG reductions) to be set for five year periods. The first carbon budget specified a GHG emissions reduction of 26 % from 1990 baseline levels by 2020. The sixth carbon budget, announced in December 2020, set more ambitious targets than any previously announced: setting the target of 68 % reduction by 2030, and 78 % reduction by 2035 (CCC, 2020e).

When issuing the 2020 Energy white paper on 14 December 2020, the UK Government stressed their aim to '*drive ambitious action'* on climate change in the run up to hosting the 2021 COP26 conference in Glasgow (BEIS, 2020c). One of the ten areas highlighted for innovation was bioenergy. The Government will carry out a review of the amount of biomass available in the UK, and in Spring 2021 issued a call for evidence to inform their 2022 biomass strategy (BEIS, 2020c; BEIS, 2021d).

Despite backing from the IPCC and CCC, bioenergy has faced criticism for failing to deliver the GHG reductions claimed by advocates, and this is briefly discussed in section 2.3.

The two most commonly grown PECS in the UK are miscanthus grass and short rotation coppice (SRC) willow, which are generally combusted in power stations or industrial plants to generate electricity and/or heat, but can also be processed by gasification or pyrolysis. Although PECs have been included in biomass potential assessments for many years, their cultivation has failed to become well established in the UK. Delivering the seventy-fold increase from the current area grown of 10 kha (DEFRA, 2020a) to the 700 kha modelled in the CCC *Further Ambition* scenario in the next thirty years seems to be an enormous challenge, particularly as there are currently no government backed schemes to promote their production, there is little coverage of the crops in the media, and public opinion is not supportive. There is clearly a role for bioenergy to play in GHG reduction, but significant action will be required to increase the supply of biomass available in the UK to the levels projected in the CCC plans.

1.4 Woodland creation, woodland management and woodfuel

Woodland creation is advocated by the CCC primarily for carbon sequestration in live trees, soil, and timber. Management of established woodland is often overlooked but is important for tree health and productivity. Sustainable management, as specified by the UK Forest

Standard (UKFS) (Forestry Commission, 2017b), includes thinning, pruning and restocking trees; and monitoring, managing and reporting on pests and diseases. Sustainable woodfuel can be produced from thinning and later from harvests, especially from broadleaved trees which may not produce useable timber. Woodfuel can deliver meaningful GHG reductions if biomass is from sawmill waste, from thinnings from sustainable management or biomass is produced from low carbon soils which would otherwise remain unused (Reid et al., 2019).

Woodland planting, whether for timber production or carbon sequestration, also delivers a range of other benefits including increased biodiversity, flood control, recreational space, and improved air quality (Forestry Commission, 2017b). However, the UK has only 13 % canopy cover, much lower than most European countries, and cover in England of 10 % and 6 % in Y&H is even lower. The UK has repeatedly failed to hit annual woodland planting targets despite grants being available to encourage new planting (Forestry Commission, 2019e). In the year 2017–18, 9,000 ha of woodland was created in the whole of the UK (Forestry Commission, 2018), with only 1,500 ha created in England, and the largest planting being 7,100 ha in Scotland. Of the 1,307 Mha of existing woodland in England, 1,093 Mha are privately owned.

As well as receiving government support, planting is promoted by charities, e.g. The Woodland Trust has pledged to plant five million trees by 2025 (Woodland Trust, 2020b) which could cover between 2,000 ha (planting at 2,500 trees per ha) and 3,125 ha (at 1600 trees per ha). In recent years woodland creation has had a high profile in the media, and the benefits are widely promoted, although the potential negative impacts are seldom discussed (Anderegg et al., 2020), and there is a risk that emphasising the benefits of tree planting can distract attention from reducing fossil fuel consumption and restoring peatland (Seddon et al., 2021).

The UK Government's target for woodland creation, currently set at 30 kha per annum (Prime Minister's Office, 2020), demonstrates that it has the will to deliver significant woodland creation, but this has not yet been converted into planting. The decision to plant will in most cases be made by individuals or families owning land, who will have to change their farmland to woodland. All woodland felling requires a licence from the Forestry Commission (FC), and in general, replanting will be required, unless felling is a part of a historic landscape or habitat restoration project (Forestry Commission 2007). As a result, almost all woodland creation will be a permanent change of land use.

1.5 The role of landowners in biomass production

In addition to the 13 % of the UK land area which is woodland (Forestry Commission, 2018), agricultural land (excluding woodland on farms) makes up a further 72 %, built up areas 6 % and urban green space 2.5 %: the remainder is wild (Rae, 2017). The vast majority of farmland is privately owned and in 2019 there were 212,000 farms in the UK (DEFRA et al., 2020). In England 40 % of the farmland is owner occupied, 17 % is tenanted and 42 % is part of a farm which is a mix of owned and tenanted land, with many of the largest farms being of mixed ownership as farmers rent additional land to allow expansion (Lobley et al., 2012). Some of the largest landowners in the UK are the FC, the National Trust and National Trust for Scotland, the MOD, The Crown Estate, utility companies (such as Yorkshire Water and United Utilities), and the RSPB (Country Life, 2010); and they rent some of their farmland to tenant farmers. The role of the landowner (individuals or institutions) and tenant is often overlooked when plans for land-use change are discussed, particularly when extremely ambitious tree planting targets are proposed by politicians (see **Box 7**) and environmental charities (see section 2.6.3).

This is a complex time for farmers, landowners, and policy makers. Having left the EU at the end of 2019, the UK is replacing subsidies from the EU common agricultural policy (CAP) with payments from the new Environmental Land Management (ELM) scheme, designed to replace subsidies for owning land and producing food with rewards for delivering environmental public goods (see section 2.6.6). The UK is also implementing a new Agriculture Bill (DEFRA, 2020f) and a new Environment Bill (DEFRA, 2020e). There is pressure to deliver a *green recovery* from the recession caused by the coronavirus pandemic (Lord Goldsmith, 2020), and the UK Government has set very ambitious targets for future decarbonisation in the lead up to the COP26 conference (CCC, 2020e). This time of great change presents ideal opportunities for new policies for net zero to be formulated and delivered, but farmers and landowners will always make the key decisions needed to change land use, and deliver climate change mitigation.

1.6 Research questions and objectives

The overall aim of this research is to assess the prospects for increasing production of bioenergy feedstocks in the UK, and to identify a set of policies that could deliver the significant increase in biomass production needed as a part of the CCC plan to reduce net UK GHG emissions to zero by 2050. This aim can be met by answering three research questions:

> *Q1. Which types of biomass have potential for increased production or use in Yorkshire and Humberside?*
>
> *Q2. What are the barriers to, and drivers for, the greater production and use of biomass for energy production?*
>
> *Q3. What policies would be effective in increasing the production and use of biomass for bioenergy to help meet the UK's net-zero target?*

1.7 Thesis structure

Chapter 2 contains background information to provide context for the research. Chapter 3 is a review of relevant literature, including biomass potentials, barriers to biomass production and use, theories which were considered for use as analysis frameworks, land use change, and policy formulation. The research methods used, the reasons for their selection and how the research was carried out are described in Chapter 4.

The results of the biomass potential evaluation for Y&H are presented in Chapter 5, which includes the identification biomass for further research. Chapter 6 contains the results and discussion of the data gathered in stakeholder interviews which were performed to understand the of use of poultry litter for bioenergy, the low level of PEC cultivation, and the failure to increase woodland planting and management in the UK. The results from the identification and analysis of land-use policies to deliver more bioenergy feedstocks in the UK are presented and discussed in Chapter 7.

Overall conclusions from the research are drawn in Chapter 8, with suggestions for further work, and a final reflection on the prospects for biomass and bioenergy in the UK, and the remaining challenges which need to be overcome if the production of biomass is to increase.

Chapter 2 Background

This chapter contains some background information needed to understand the research carried out. The topics include introductions to: the Yorkshire and Humberside region, types of biomass, bioenergy generation technologies, the GHG emissions from bioenergy, carbon capture and storage (CCS), and the impact of land use change. It also provides the policy context for bioenergy, summarising the incentives that have been available for PEC cultivation and renewable energy generation in the UK, targets set for woodland management and creation, and the incentives available for delivering these targets. Carbon trading and payments for environmental services are also outlined.

Further background information is introduced in boxes in the results chapters at points where it becomes pertinent.

2.1 Leeds and the Yorkshire and Humberside region

Much of the research described in this thesis focusses on the City of Leeds, and the Yorkshire and Humberside (Y&H) region (also known as Yorkshire and the Humber). **Figure 2.1** shows the location of Y&H in the north east of England. Y&H was a Government Office Region until these were abolished in 2011, and although it now has no administrative role, it remained one of the nine EU NUTS (Nomenclature of Territorial Units) Level 1 regions of England (ONS, 2016a), and many regional statistics are produced at this level. Y&H contains the large cities of Leeds, Bradford, Sheffield, and Hull but also contains fertile farmland in the centre, south, and east, with lower quality land on the Pennine Hills in the west, the Yorkshire Dales in the north west, and the North Yorkshire Moors in the north. The Leeds City Region (LCR) is a sub region of Y&H and comprises Leeds, Bradford, Barnsley, Calderdale, Craven, Harrogate, Kirklees, Selby, Wakefield, and York. It has a single Local Enterprise Partnership, a '*non-statutory body which brings together private and public sectors from across the LCR, to provide strategic leadership to drive economic growth and competitiveness*' (Leeds City Region Enterprise Partnership, 2018), but is not a NUTS reporting area. **Figure 2.2** shows all the local authority areas in the Y&H region and highlights the position of Leeds in the LCR.

It has been estimated that in 2018 the population of Leeds was 789,194, LCR 3,081,777 and Y&H 5,479,615, out of a population of nearly 56 million in England (ONS, 2020).

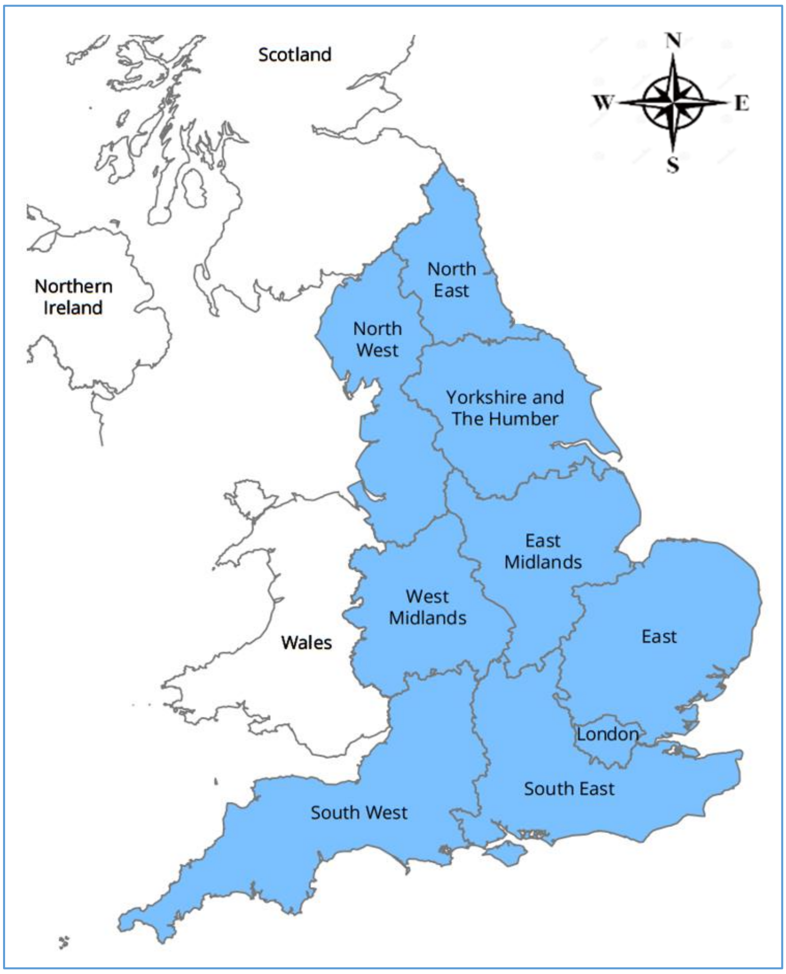

Figure 2.1 Map of the NUTS 1 regions in England
Adapted from ONS (ONS, 2017).

Y&H contains 12.5 % of the farmland in England, and the proportion of this land used for arable farming at 52 % is the same as for England as a whole, while the proportion of pasture land is 35 % in Y&H and 36 % in England. The average size of a farm in Y&H is 93 ha, slightly larger than the English average of 86 ha, but average farm incomes are lower: £45 k in Y&H and £50 k in England. Y&H appears to be representative of farming as a whole in England, except for having less dairy farming and more pig farming than average (being home to 37 % of the English pig population) (DEFRA, 2021a).

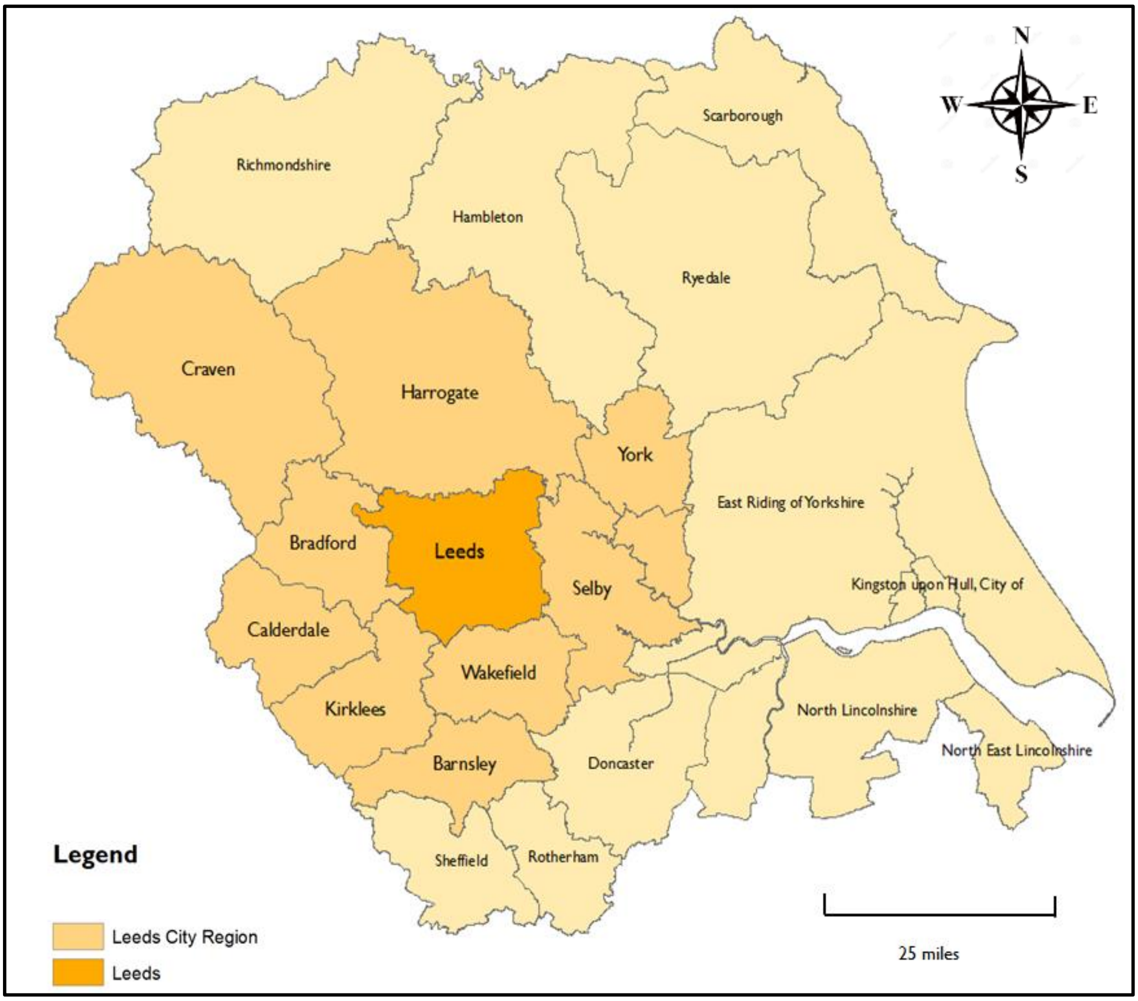

Figure 2.2 Map of all the local authorities in the Y&H region
Indicating Leeds within the Leeds City Region. Base map (ONS, 2016b).

2.2 Bioenergy

2.2.1 Biomass

Biomass (or biorenewable resource), is organic material of recent biological origin, obtained from the biosphere, which has derived its energy content from sunlight, and this stored energy content can be used to generate bioenergy including heat, electricity, and biofuels (Brown and Brown, 2014). The main types of biomass available for energy use have been defined by the UN (FAO, 2004) and the these are shown in **Table 2.1**, together with examples of each type of biomass arising in the UK, and the types of technology that can process it. These types of biomass are described briefly in the following sections, and processing technologies are outlined in section 2.2.2.

Table 2.1 Biomass types and processing technologies in UK
Developed from FAO classification scheme (Rosillo-Calle et al., 2007; FAO, 2004).

FAO Common Group	Biomass types - FAO Production Side Supply	Examples of UK Biomass types	Processing technologies
Woodfuels	Direct woodfuels	virgin wood logs, woodchips, wood pellets	thermal
	Indirect woodfuels	sawmill waste: sawdust, pellets	thermal
	Recovered woodfuels	demolition and construction waste, municipal waste wood	thermal
Agro-fuels	Fuel crops	energy crops for thermal processing: miscanthus, SRC	thermal
		energy crops for AD: maize, rye, grass	AD
		energy crops for biofuels: wheat	fermentation
		crops for oil: oil seed rape	esterification
		algae: seaweed	AD or fermentation
	Agricultural by-products	straw and husks	thermal and AD
	Animal by-products	cow and pig manure	AD
		poultry litter	thermal and AD
Municipal by-products	Municipal by-products	biogenic fraction of MSW	thermal and AD
		processing, hospitality, and household food waste	AD
		waste cooking oils	purification
		sewage sludge	AD
		landfill gas	thermal

2.2.1.1 Woodfuels

The many sources of woodfuel include virgin wood from sustainably managed woodland, supplied as logs, wood chips, or pellets for combustion (Forestry Commission, 2017c). Some of the co-products from timber sawmills can also be used as fuel, as can recovered waste wood (from domestic and commercial sources including construction and demolition) and arboricultural arisings (the products of felling and pruning of trees in built up areas and transport corridors (Forestry Commission, c2006)).

Short rotation forestry (SRF) (also known as energy forestry) is the cultivation of fast growing native or exotic tree species in plantations to produce woodfuel. Trees are planted at very high densities and managed as conventional single stem trees rather than coppiced woodland, and can be harvested after 8–20 years (McKay, 2011).

2.2.1.2 Agro-fuels

The two main types of agricultural (agro) fuels are by-products from crops and livestock farming, and energy crops grown specifically for energy production.

Straw, the residue from cereal crops such as wheat, barley, and OSR, can be harvested and is generally used for combustion, but can also be used in AD. In the UK the main competing demands for straw are for animal bedding and for over wintering carrots (AHDB, 2018c). Cattle and pig manure, and poultry litter can be used as AD feedstocks, or used as organic fertilisers. Poultry litter is discussed in more detail in the next section.

The crops grown, and technologies used, for producing biofuels, such as biodiesel or bioethanol can be classified as first, second or third generation. First generation crops, which were food crops such as wheat and sugar, caused a great deal of concern about their impact on food production. Second generation feedstocks were then favoured, including non-food crops which can be grown on poorer quality land, crop by-products, and wastes, which provide less competition with food production. Third generation energy crops include microalgae (Glithero et al., 2013b; Royal Academy of Engineering, 2017). Crops grown for transport biofuels are not included in this research, but the potential for demand for land to cultivate them should not be overlooked.

Annual energy crops cultivated in the UK include maize, rye, barley, beet, and wheat. The two most commonly grown perennial energy crops (PECs) are miscanthus and willow, which are described below in sections 2.2.1.2.2 and 2.2.1.2.3. In the UK no crops are currently grown to produce biodiesel (see **Figure 1.2**): instead, only waste oils and fats are used as feedstocks. Some bioethanol is produced from wheat and sugar beet and in 2018, 22 kha of wheat and 5 kha of sugar beet were grown for energy. In the same year 57 kha of maize was grown for anaerobic digestion, and 7 kha of miscanthus and 3 kha of short rotation coppice were grown for combustion (DEFRA, 2019b).

2.2.1.2.1 Poultry Litter

Poultry litter is a mixture of faeces, bedding material and uneaten feed, and can be combusted in power stations, or on-farm to generate heat or combined heat and power (CHP). The quantity, composition and energy content of litter depends on the species of bird, the type of farming being carried out, the type of bedding and the farming practices (Compassion in World Farming, 2013; Compassion in World Farming, 2012). Of the 188 million bird places in the UK (DEFRA et al., 2019) most are chickens, with smaller numbers of turkeys, ducks, geese and pheasants. Most litter is produced from broiler chickens – the chickens grown from day old chicks for about six to eight weeks and sold for meat. In the UK, litter is removed from broiler sheds at the end of each crop. Litter from breeding birds that produce chicks, and from egg-laying birds, can also be used for energy but their litter has a lower calorific value. Farmers can either arrange cleaning and removal of litter separately, or can use a contractor or litter merchant e.g. Pedersons (Pederson Contracting Services, n.d.) to clean the shed and remove all the litter free of charge. The merchants then trade poultry litter: supplying power stations and AD plants as well as farmers who want fertiliser.

The traditional method of disposing of poultry litter was to spread it on land, which incurred disposal costs, and some excess litter was sent to landfill (Dagnall, 1993). However, storing and then land-spreading litter can cause environmental problems (Bowen et al., 2010), including pathogen contamination, and odours. The high nitrogen (N) and phosphorus (P) content can cause ammonia toxicity, eutrophication, and crop toxicity (Lynch et al., 2013; Bolan et al., 2010; Dalólio et al., 2017). Storage and spreading of litter are regulated in the UK by DEFRA, with stricter limits on spreading in designated Nitrate Vulnerable Zones (NVZs), where waterways are at risk of contamination from nitrates. Much of the low lying land in Y&H is classified as a NVZ (EA, 2020).

Combustion of poultry litter was initially viewed as a method of litter disposal which produced a more stable potassium (K) and P fertiliser with no N content (Szogi and Vanotti, 2009), as well as a method of generating energy. However, ash from combustion, having lost the humus from the litter, is not a soil conditioner, and farmers value the soil improvement delivered by poultry manure (Case et al., 2017). The value of the N, P and K (the three key elements of fertiliser) content of poultry litter has been estimated at £21 per tonne (AHDB, 2018b), and this is likely to limit the price that will be paid for litter by farmers.

Combustion trials were held in the 1990s, when farmers who could not use the litter as fertiliser on their own land were paying between £0.50 and £5.00 per tonne for disposal (Dagnall, 1993). Litter combustion power stations were built in the 1990s at Thetford, Ely, Eye and Westfield (Fife) (Kelleher et al., 2002) and are still in operation (BEIS, 2017a; Melton Renewable Energy UK Limited, 2016). Litter combustion is also carried out in Eire (Lynch et al., 2013), the USA (MacDonald, 2008) and the Netherlands (Billen et al., 2015). Litter has a higher ash content than other biomasses (Lynch et al., 2013) such as wood and can cause problems in combustion (Lynch et al., 2013; Bowen et al., 2010; Bolan et al., 2010).

Research on the use of poultry litter for bioenergy is reviewed in section 3.3.

2.2.1.2.2 Miscanthus

Miscanthus is a giant grass grown from rhizomes which produces tall stems, which can be harvested from two or three years after planting, for a period of 10 to 15 years. These stems are harvested annually in winter and combusted in power stations. Crops of miscanthus are resistant to cold weather and require a low input of fertiliser as they return nutrients to the ground through leaf fall, and to the rhizomes as the leaves die (senescence). They can be grown on marginal, poorer quality agricultural land that would otherwise not be economic or suitable for cultivating food crops (Robson et al., 2020; Clifton-Brown et al., 2019). Miscanthus has been shown to have a positive environmental impact. Planting miscanthus on former arable land has a neutral or positive impact on soil carbon storage, and although planting on former semi-permanent pasture causes a temporary reduction in soil carbon, this is recovered as the plants establish. N_2O emissions are far lower than from fertilised crops, biodiversity is enhanced, and the use of miscanthus as a replacement for fossil fuel results in significant reductions in GHG emissions (McCalmont et al., 2017), even without CCS.

Miscanthus breeding research began in the 2000s to create higher yielding and more resilient breeds. Hybrid cultivars that can be established from seed, rather than rhizomes, could be ready for market by 2022, which would allow much more rapid scaling up of miscanthus cultivation than is currently feasible (Clifton-Brown et al., 2019). Current European research on miscanthus includes the GRACE (GRowing Advanced industrial Crops on marginal lands for biorEfineries) project (GRACE, 2020) which includes academic and industrial partners from the EU and UK, with the aim of optimising value chains for bio-based products.

2.2.1.2.3 Willow short rotation coppice

Short rotation coppice (SRC) trees, usually willow or poplar in the UK, can be grown as a perennial crop. Willow takes up to four years to establish and can be coppiced (cut back to ground level) every three years from then onwards (Glithero et al., 2013a) for between 22 and

30 years (Clifton-Brown et al., 2019), to produce biomass for combustion. Willow crops can act as net carbon sinks because of their ability to fix carbon in soils, they improve biodiversity (Harris et al., 2017; Weih et al., 2019; Cunniff et al., 2015), can control flooding, and increase soil stability (Alderton, 2018; Nisbet et al., 2011). Willow breeding research has been under way in the UK since the 1920s to improve yield (Clifton-Brown et al., 2019).

2.2.1.3 Municipal by-products

The organic fraction of municipal solid waste (including food waste, wood, fabrics, paper, and sanitary items) can be used to generate energy. It is often combusted with the non-organic fraction (including any plastics not extracted for recycling) in energy from waste (EfW) plants. Domestic and industrial food waste can be separated and used as an AD feedstock, waste wood is sometimes separated for combustion in dedicated wood burning plants, and waste oils and fats are used to produce biodiesel (DEFRA, 2017b; DEFRA, 2013a; AEA Energy & Environment, 2007; Williams, 2005).

Biodegradable materials in landfill sites degrade to produce landfill gas which contains about 60 % methane. In a well-constructed landfill site the gas can be captured and combusted to generate heat, electricity, or CHP, or cleaned up and injected into the gas grid (Williams, 2005). The introduction of the Landfill Tax in 1996, which from April 2021 is £96.70 per tonne (HM Revenue and Customs, 2017), has led to a reduction in the amount of biodegradable waste in landfills, and the supply of landfill gas has already started to decline (BEIS, 2017a).

Sewage sludge is a by-product of raw sewage treatment and can be used as an AD feedstock (Williams, 2005).

2.2.2 Biomass processing technology

The main biomass processing methods in the UK are: anaerobic digestion (AD), thermal processes (combustion, pyrolysis, and gasification), and the production of biofuels such as bioethanol and biodiesel used for transport.

2.2.2.1 Anaerobic digestion

Anaerobic digestion (AD) is the decomposition of organic matter into simpler compounds by bacteria and archaea, in an oxygen-free aqueous environment, using feedstocks such as the organic fraction of municipal solid waste (MSW), and animal manure (Brown and Brown, 2014). Energy crops, chicken litter, food waste and straw can also be digested. AD produces biogas comprising approximately 60 % methane and 40 % carbon dioxide, with small amounts of other gases such as hydrogen sulphide, nitrogen, and oxygen. The biogas can be upgraded to biomethane by removing the other gases and can then be fed into the gas grid, or it can be burned without upgrading to generate heat or CHP (Halford, 2015). The solid residue, the digestate, contains the majority of the nutrients in the feedstocks and can be used as a bio-fertiliser (Salter et al., 2007). AD has an important agricultural role for treating waste as well as being a renewable energy technology (Röder, 2016).

2.2.2.2 Thermal processes

Thermal processes can be used for solid wood, wood chips, wood pellets, MSW, straw, grasses, and chicken litter biomass feedstocks.

Combustion is the rapid oxidation of fuel to release energy. It requires a good supply of oxygen and can reach temperatures of over 1650°C producing heat, CO_2, water vapour and ash (Brown and Brown, 2014). The heat from combustion can be used to drive turbines to generate electricity. Biomass can be combusted alone, or co-fired with coal, as was the practice in the UK during the transition from coal to biomass combustion. Co-firing was abandoned as power stations switched to 100 % biomass as coal use in the UK comes to an end. At Drax power station in Selby, North Yorkshire, four of their six units were converted to 100 % biomass combustion by the end of 2018 (Drax Group plc., 2017), coal-powered Ferrybridge 'C' has closed, and new biomass combustion plants have been constructed on the site. Another coal powered plant, Eggborough, closed in 2018 (BEIS, 2017a). Small scale combustion can deliver heat from domestic wood-burning stoves, and larger boilers can be used to heat buildings such as schools and hotels, or to drive district heating systems.

Gasification is the processing of biomass at high temperatures (generally 750 to 1500°C) with a limited oxygen supply, to produce flammable synthesis gas (syngas) or producer gas, which is a mixture of carbon monoxide, hydrogen, methane, nitrogen, carbon dioxide, and contaminants. Producer gas can be used to generate heat and power by combustion, or as a feedstock for chemical processes. Pyrolysis is the decomposition of organic compounds in the absence of oxygen at elevated temperature, and produces liquid oils, gases (as produced in gasification) and solid char. The products can be used for energy generation or as chemical feedstocks (Brown and Brown, 2014). Gasification and pyrolysis are often described as advanced conversion technologies (ACT) but there are '*known to be technical issues'* (BEIS, 2017a) with large scale ACT plants in the UK and combustion remains the dominant thermal technology in the UK.

2.2.2.3 Biofuel production

Bioethanol can be produced by fermenting sugar or starch from crops such as maize, wheat and sugar beet (Brown and Brown, 2014) or from waste sugar/starch residues. It can be blended with petrol in low proportions for use in petrol engines. Currently petrol sold in the UK can contain up to 5 % bioethanol or up to 10 % if appropriately labelled, and from

September 2021, 10 % bioethanol will become standard (DfT, 2021a). In 2015/16 about 20 % of bioethanol consumed in the UK was supplied from waste feedstocks (BEIS, 2017a). Biodiesel can be produced from biological sources of oils and fats, such as rape seed oil and waste fats and oils, by transesterification (Brown and Brown, 2014) and can be blended with fossil diesel. In the UK in 2019 the feedstock for biodiesel consumed in the UK for transport was almost entirely waste fats and oils. That year 5.3 % of diesel was biodiesel, 4.5 % of petrol consumed was bioethanol, and more than half of the biodiesel and bioethanol was imported (BEIS, 2020b).

In the future, as petrol and diesel engines in road vehicles are replaced by electric motors, biofuels are expected to be used only as a replacement for aviation kerosene (CCC, 2019). Heavy goods vehicles and buses pose a more difficult decarbonisation challenge than cars and vans, and options including hydrogen fuel cells, batteries, and overhead charging are being assessed (CCC, 2020b; BEIS, 2020c). The Government has given a clear signal that in future biofuels should be produced from wastes and not dedicated energy crops, and the percentage of non-waste feedstocks has been capped (DfT, 2020a).

Biofuels are not considered in this research, which focusses on bioenergy for heat and power.

2.3 GHG emissions from bioenergy

Bioenergy has been a key part of global efforts to mitigate climate change by reducing the GHG emissions from energy generation. Biomass is often considered to be a carbon neutral fuel as the CO_2 released on combustion is recaptured when biomass crops are regrown (Gough et al., 2018), and this is enshrined in EU legislation (European Parliament, 2015). Although this is a reasonable claim for annual crops (Röder et al., 2019), it can take many years for some biomass systems, including wood combustion, to become carbon neutral (Sterman et al., 2018). The factors affecting the emissions from bioenergy include farming or forestry practices, biomass transport distances, storage, pre-treatments, land use changes and their impact on soil carbon, and a wide range of counterfactuals (Gough et al., 2018). Sustainability criteria have been applied to biomass feedstocks in the EU (European Commission, 2010) and UK (OFGEM, 2018c; OFGEM, 2017a) in an effort to improve the sustainability of biomass production and use.

The impact of any bioenergy system on climate mitigation can only be fully understood by carrying out a rigorous lifecycle assessment (LCA) of carbon emissions, and modelling the carbon in soils and forests (Röder et al., 2019; Röder et al., 2015). The results from LCAs are highly dependent on the assumptions made and boundary conditions (such as selecting a landscape scale assessment or smaller scale), and the period of time over which the carbon debt is considered (Gough et al., 2018).

This is a complex issue which has provoked much discussion (Mather-Gratton et al., 2021) and it will not be dealt with here. However, it must be noted that the debate over the sustainability of bioenergy has resulted in active opposition from many quarters: from groups such as *Biofuel Watch (2021),* Ember (2020a) and *Cut Carbon Not Forests* (2021), from some academics (Beddington et al., 2017), articles in the press (Sheffield, 2021) and from environmental charities (RSPB, 2011; RSPB et al., 2012).

Opposition to biomass use in cities, and at small scale in wood burning stoves, has grown because of the impact on air quality (Mitchell et al., 2017; Holland, 2018) leading to restrictions on wood burners in cities (DEFRA, 2019c).

Despite opposition to the use of biomass, large scale sustainable bioenergy with carbon capture and storage (BECCS) is included in many global and UK net zero pathways (IEA, 2021; Energy Technologies Institute, 2018; CCC, 2018a) including those of the IPCC (IPCC, 2018), as a means to not only reduce GHG emissions, but to deliver negative emissions by capturing the CO_2 released from combustion.

2.4 Carbon capture and storage (CCS)

GHG removal from the atmosphere involves capturing the gas and then storing it for an extended period. Biological uptake through photosynthesis in trees and plants can allow carbon to be stored in forests, in timber products, and in soils. If biomass (containing carbon recently sequestered from the atmosphere) is combusted for heat or power production, the CO_2 emitted on combustion can be captured and stored in geological reservoirs such as the depleted gas reservoirs in the North Sea, delivering bioenergy with carbon capture and storage (BECCS) (Royal Society and Royal Academy of Engineering, 2018). The CCC proposes using PECs for large scale BECCS, generating electricity with heat where possible, to deliver the negative carbon emissions needed to compensate for hard to decarbonise sectors such as agriculture and aviation (CCC, 2019).

Bui et al. (2018) observed that there is little lobbying for or against CCS, and until the Government acts to support CCS little progress will be made in the UK. However, the prospects for CCS look more certain now the Government has increased funding of CCS deployment to £1 billion by 2025, to deliver operational CCUS in four industrial clusters (HM Government, 2020). The CCC has recommended that CCS should be deployed at all EfW plants during the 2030s (CCC, 2020b). As well as overcoming technical challenges BECCS will need strong policy support (Babin et al., 2021; Bellamy et al., 2021), and possibly direct investment from the Government, and a viable carbon trading scheme to make it financially viable for generators (Galik, 2020). Gough (2018) warns that relying on BECCS could divert efforts from decarbonisation of industries.

2.5 The impact of land-use changes on carbon stocks and emissions

Soils are natural regulators of atmospheric CO_2 and store two to three times more carbon than the atmosphere. The amount of carbon sequestered in agricultural soil can be increased in many ways e.g. reducing tillage intensity, applying manures, and incorporating crop residues (Abbas et al., 2020). Tree planting and management practices need to minimise soil disturbance to prevent GHG release, especially on soils with a high carbon content (Morison et al., 2012). Any change to land use can result in either a gain or a loss of soil carbon from both direct and indirect land-use changes, and PECs should be grown on mineral soils (with a very low organic matter content) to minimise short term carbon losses, and to promote carbon sequestration in the long term (Whitaker et al., 2018). The land use and land-use change and forestry (LULUCF) sector is currently the only one which can achieve negative emissions (CEH and Rothamsted Research, 2019) through sequestration of carbon in either soils or plant biomass.

Peat soils are very high in organic matter and if they dry out, either naturally or when drained for agricultural or forestry use, this can result in oxidation of soil carbon releasing CO_2, and the release of methane from drainage water (Page et al., 2020; Mulholland et al., 2020). Restoring and rewetting peat soils can eliminate GHG emission and instead create a carbon sink (Crosher and Morecroft, 2020).

2.6 Policies and targets

2.6.1 Policies supporting energy crop cultivation

No subsidies are currently available for growing energy crops, but support was available until 2013. The Energy Crops Scheme (ECS) supported miscanthus and SRC planting from 2000 to 2006, and then a second scheme (ECS2) was available from 2007 until 2013. £76 M was available in total but both schemes were under-subscribed (NNFCC, 2012a; Lindegaard, 2013). The Bioenergy Infrastructure Scheme provided grants from 2005 to 2009 to develop the supply chain required to harvest, process, store, and supply biomass to users. EU set-aside grants were payable from 1992 to 2008 on energy crops grown on set-aside land, and for 6 years from 2003, energy crops on non-set-aside land were also eligible for *Energy Aid Payments,* which were mainly made for OSR (Adams and Lindegaard, 2016; Mawhood et al., 2015). Not only did these schemes fail to deliver significant planting, but by providing a flat subsidy based on the area of crop planted they did not encourage careful husbandry, and poor quality establishment and yields resulted (Mawhood et al., 2015).

The latest Government strategy for bioenergy, issued in 2012, stressed the key role that bioenergy has to play in decarbonisation, and recognised that the benefits of energy crops include their ability to prevent soil erosion, improve biodiversity and improve fuel security (DfT et al., 2012). However, no targets or assistance for PECs have resulted. In December 2020 the UK Government announced their plans for carrying out a UK biomass potential assessment and reviewing the best use of biomass (considering use for energy and as chemical feedstock) as a part of the biomass strategy to be issued in 2022 (CCC, 2020b; BEIS, 2020c).

2.6.2 Woodland management targets and policies

Managing woodlands sustainably generates income for landowners from timber and woodfuel, helps to control pests and diseases, and encourages biodiversity (RFS, 2019; Forestry Commission England, 2010; Gabbatiss, 2020b). The carbon debt incurred from management is mitigated by the increased vigour of the remaining trees, the production of timber and replacement of fossil fuels by woodfuels (Vance, 2018). The net effect of managing UK forests to produce a mix of wood products and woodfuel results in more carbon storage than leaving them unmanaged (Forest Research and North Energy, 2014). Under-management leads to low productivity and failure to identify pests and diseases, but it persists, despite efforts to persuade land managers to bring their woodlands in to management.

The *Woodfuel Strategy for England* was defined by the FC at the request of the UK Government (Forestry Commission, c2006). It aimed to bring 2 million tonnes per annum of sustainably produced wood (half the unharvested annual biomass increment) to the market from under-managed woods, recovered wood, and arboricultural arisings. It proposed using woodfuel for local heat production and for small to medium CHP, and improving awareness of the need to manage woodland. These actions were expected to deliver the benefits of mitigating climate change, improving biodiversity and fuel security, and stimulating economic development.

Later targets were set in terms of area of woodland managed sustainably. The Government set a target of 67 % of English woodlands to be managed by 2018 but progress towards the target was slow and reached only 59 %. There is significant doubt as to the true level because estimates are based on management plans and felling licences, and although these may be in place they may not be acted upon (RFS, 2019).

The *Woodland Management Plan Grant* is available to landowners as a part of Countryside Stewardship to fund the creation of sustainable management plans (Rural Payments Agency, 2020). Other policies that could encourage woodland management include a wide range of education, information, and advice measures, and also subsidies for building forest access roads. Successful policies need to be tailored to local social, environmental, economic, and political conditions (Lawrence, 2018), and different types of woodland owner (Urquhart and Courtney, 2011).

2.6.3 Woodland creation targets and policies

Woodland cover in the UK fell to a low of 5 % after the First World War, and the Forestry Commission was founded in 1919 to ensure that future shortages of wood would not occur. Planting for a century has resulted in UK cover rising to 13 %, but this is not evenly distributed with Scotland having 18 %, England 10 %, Wales 15 %, and Northern Ireland (NI) 8 % woodland cover (Forestry Commission, 2017b). Tree planting reached its peak during the 1970s when over 40 thousand hectares were planted each year, mainly in Scotland and mainly plantations of conifers. At this time the FC was planting significant areas to expand the nationally owned forests (Forestry Commission, 2019a).

Figure 2.3 shows the levels of planting achieved in the UK since 1971. Planting dropped dramatically from the mid-1970s when tax advantages for conifers were removed. It can be seen that some recovery of planting in England was achieved in the early 1990s when incentives to plant were available from the Woodland Creation Grant and Farm Woodland Schemes provided income-foregone payments. However, planting in England declined again under the 2007 English Woodland Grant Scheme and fell to 700 ha in 2015 when the Countryside Stewardship Grant Scheme was introduced (Forestry Commission, 2019a).

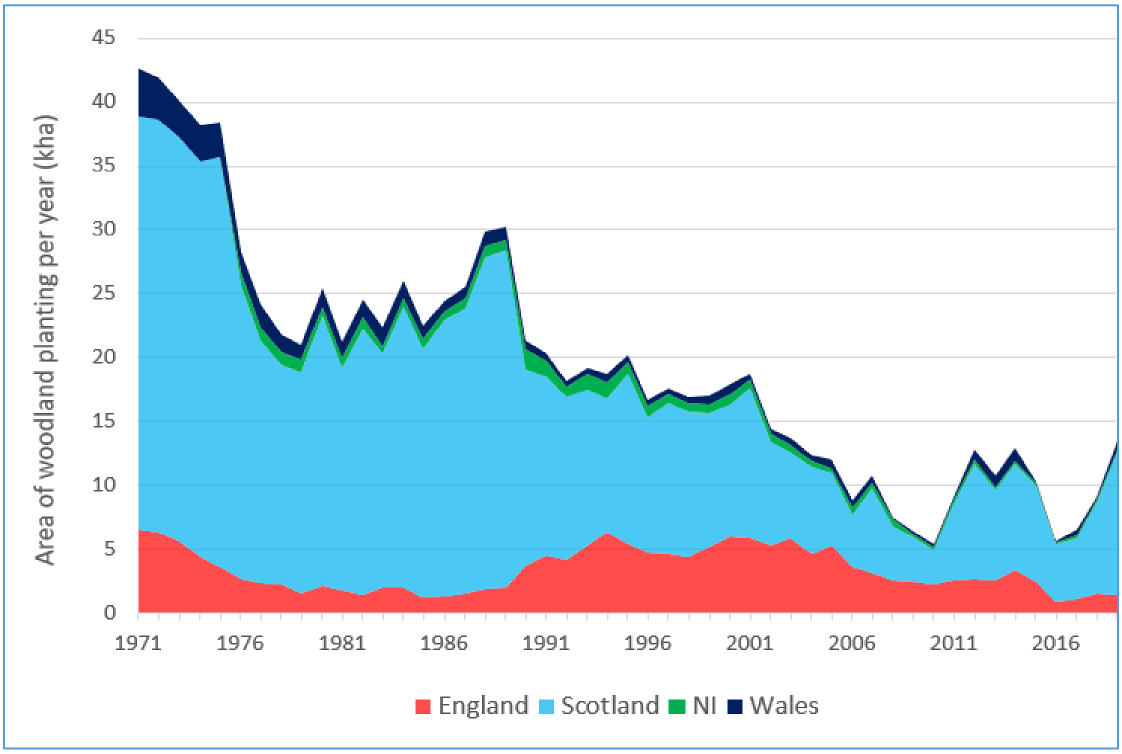

Figure 2.3 Annual woodland creation in the UK by country
Data from Forest Research (2020b).

Many targets have been set for planting in the UK and England. Following an assessment of the role that forests could play in mitigating climate change, Read et al. (2009) proposed planting 23 kha of new woodland per annum for 40 years to increase the woodland cover to 16 % of the UK land area and to deliver abatement of 10 % of annual GHG emissions. The Government set the target of 6,200 ha per annum by 2030 as a part of the 25 year Environment plan (HM Government, 2018). Other UK targets for 2030 have been proposed such as 40 kha per annum by the World Wide Fund for Nature and by Confor[1], 100 kha per annum by Friends of the Earth (Confor, 2019b) and 48 kha per annum by the Woodland Trust (2020a). Confor splits their 40 kha per annum by 2030 target between the four UK nations; 18 kha in Scotland, 10A kha in England, 9 kh in Wales, and 3 kha in NI (Confor, 2019b).

Although levels of planting of over 30 kha per year were achieved in the 1970s and 1980s, these targets are clearly significantly above current planting levels. The Government target currently stands at 30 kha per annum as confirmed by the Prime Minister, Boris Johnson, in November 2020 as a part of the Government's ten point plan to address climate change (Prime

1 The Confederation of Forest Industries (Confor), is the trade association for the forestry industry in the United Kingdom.

Minister's Office, 2020). The latest figures available show that between 1 April and 30 September 2020, 763 ha of woodland were created (about 1,324,000 trees) in England with central government support, down from 1,045 ha for the same period in 2019 (Forestry Commission, 2020b). Although this was presented by the press as a failure to hit targets (Webster, 2020) most planting should be carried out when the tree is dormant, generally from around mid-November to early March (Forest Research, 2020a) so the figures for the following six months will be of more interest.

Sources of grants for woodland creation or improvement in England include: *Countryside Stewardship*, *Countryside Productivity Scheme*, *Rural Development Programme for England*, *Forestry Innovation Fund Woodland Creation, and Woodland Carbon Fund*. A comprehensive summary of grants has been produced by the Forestry Commission (2019e). The *Woodland Carbon Guarantee* is of particular interest. It provides a guaranteed income for landowners from selling carbon units allocated for sequestered CO_2 at stages throughout the life of the woodland. The price awarded for carbon is set at auction (Forestry Commission, 2020c; Forestry Commission, 2020d). Assistance with planning for community planting is available from the Woodland Trust (2021) and local charities e.g. Yorkshire Dales Millennium Trust who have a target to plant 1.5 million trees in the Dales (Yorkshire Dales Millennium Trust, 2020).

Owners of woodland are also supported by preferential tax treatment e.g. they are exempt from capital gains tax on the value of trees but not for the land on which they grow. Income from the sale of timber from commercial woodlands is exempt from income and corporation tax (Forestry Commission et al., 2018). The value of the trees, but not the value of the land on which they are growing, is exempt from inheritance tax (Valuation Office Agency, 2017).

The Government published the England Trees Action plan in May 2021 (DEFRA, 2021b) which included the announcement of the England Woodland Creation Offer, to be launched in Spring 2021, to reward multiple benefits of woodland creation. It also commits to expanding the nation's forests through leasehold agreements between Forestry England and owners of land suitable for afforestation, but full details were not available at the time of writing.

2.6.4 Support for bioenergy generation

Financial incentives, funded by levies on fuel bills, are available in the UK to encourage the generation and use of renewable energy. The first support for bioenergy came from the *Non Fossil Fuel Obligation* (NFFO) when energy crops were included in a special band from 1994, and later from the *Renewables Obligation Scheme* (RO) (Mitchell and Connor, 2004; Thornley and Cooper, 2008). The RO scheme to support large generators for 20 years was open to entrants from 2002 to 2017 (OFGEM, 2020b; Adams and Lindegaard, 2016). The *Contracts for Difference* (CfD) scheme (BEIS, 2017b) now supports large generators of renewable power.

From 2010, feed-in tariff (FIT) payments were paid for a term of 20 years to small-scale generators of electricity, including AD (OFGEM, 2016), for electricity generated which may then be used by the generator or sold. This scheme closed to new entrants in 2019 (OFGEM, 2020a).

Renewable Heat Incentive (RHI) payments could be claimed by domestic and non-domestic users of renewable heat (OFGEM, 2015). The aim of these payments was to encourage users of fossil fuels, such as oil, for heating, to move to renewable fuels, such as wood pellets, or to use heat pumps. The RHI was payable on heat from the combustion of biogas, and also for biomethane injected into the gas grid. AD plants must now use at least 50 % waste feedstock to claim the full RHI and FIT payments (OFGEM, 2017a). The Government planned to close the RHI scheme in 2021; however, it has extended the domestic scheme until 2022 and has completed consultation on the replacement scheme for supporting renewable heat (BEIS, 2020e). Domestic heating is likely to be supported by the *Clean Heat Grant* which will primarily aim to support heat pumps. The 2020 Energy White paper includes the introduction of a *Green Gas Support* Scheme to run from 2021 for four years with the aim of trebling the production of biomethane (BEIS, 2020c; BEIS, 2021b). This follows a period during which the AD industry has stagnated.

The Renewable Transport Fuel Obligation (RTFO) scheme started in April 2008, and is intended to deliver reductions in CO_2 emissions from transport by encouraging the supply of renewable fuels including biomethane, biodiesel, bioethanol and hydrogen. Tradeable *Renewable Transport Fuel Certificates* (RTFCs) are issued to producers of renewable fuels, and fuels from feedstocks which are classed as a waste are awarded increased allocations of RTFCs (DfT, 2020c). The government views the scheme as being successful in driving up the renewable content of transport fuel (DfT, 2020b) and plans to increase the target of renewable transport fuels to 14.9 % by 2032 (DfT, 2021b).

2.6.5 Carbon trading and off-setting

The *EU Emissions Trading Scheme* (EU ETS) is a cap and trade scheme, which caps the allowable emissions from power generation, energy intensive industries, and aviation. It allows trading of allowances so that emissions reductions are made where it is cheapest to do so. The allowances in phase III, running from January 2012 to December 2020, were reduced by 1.74 % each year (UK Government, 2020; EU, 2020). The scheme was criticised for being prone to leakage (emissions were exported out of the EU when polluting industries relocated and goods were imported), and not working when its carbon prices were low (Helm, 2014): prices in 2014 were between €3 and €6 per tonne of CO_2. Reforms were introduced and prices rose significantly from 2018, and in 2019 were trading at over €25 per tonne of CO_2 (EMBER, 2020b), before falling again in Q1 and Q2 of 2020, as a result of the coronavirus pandemic. The carbon price hit a record high of over €31 per tonne of CO_2 on 11 December 2020, in expectation of the EU setting tougher targets for cutting emissions (Sheppard, 2020).

The UK planned to stay in the EU ETS until the Brexit transition period at the end of 2020. In June 2020 the Department for Business, Energy & Industrial Strategy (BEIS) announced plans for a post-Brexit *UK Emissions Trading Scheme* (UK ETS) that would operate in a very similar way to the EU ETS and continue to cover about a third of UK GHG emissions, but would force larger emissions cuts than the EU ETS. Links between EU ETS and the UK ETS were a part of the Brexit negotiations and a separate carbon tax was another option for the UK post-Brexit (BEIS, 2020f). The new UK ETS came in to effect on 1 January 2021 (BEIS, 2021c), with the first auctions in May (BEIS, 2021e), when prices exceeded £50 per tonne (higher than the EU ETS prices) (Twidale, 2021).

Carbon sequestered by woodlands is not included in the EU ETS, but the UK the *Woodland Carbon Code* is a government backed voluntary standard that allows the creation of verifiable *Woodland Carbon Units* (WCU) each representing the sequestration of a tonne of CO_2 which can be traded (Woodland Carbon Code, 2019). The *Woodland Carbon Guarantee* scheme is an attempt to stimulate a carbon market for woodland, see section 2.6.3.

2.6.6 Payments for environmental services (PES)

Making payments for environmental services is a way of promoting the delivery of environmental benefits or public goods (see section 3.8.1 for a definition), such as carbon sequestration. Ecosystem services (ES) are '*the benefits people obtain from ecosystems*' (Millennium Ecosystem Assessment, 2005, v), and can include the *provisioning services* of food, water, and timber; and *regulating service*s such as carbon sequestration regulating the climate. Wunder (2005, p. 3) provides the widely used definition of *Payments for Ecosystems Services* (or *Payments for Environmental Services*) (PES) as voluntary transactions in which a well-defined environmental service (or a land use likely to deliver that service), is bought by one or more buyers from one or more providers, if and only if the provider continuously provides the service.

Although some voluntary sequestration of carbon does take place, governments usually need to offer PES to encourage the delivery of carbon sequestration and other environmental services. UK *Countryside Stewardship* and the new ELM are both examples of PES schemes operated in the UK.

It is generally recommended that PES should be high enough to make a land-use change financially attractive, while avoiding paying for services that are already cost effective. They should not pay more than the service is worth (although the value can be hard to quantify) and should only be delivered by the most suitable land, so the service can be delivered most efficiently and at lowest cost. They should deliver *additionality* (i.e. deliver services that would not otherwise be delivered), should avoid leakage (the displacement of the polluting activity elsewhere) and deliver a permanent benefit (Engel et al., 2008). PES schemes provide direct payments for desirable outcomes but they need to be carefully designed for each situation to ensure successful delivery of the desired outcomes (Jack et al., 2008).

2.7 The challenges facing UK bioenergy

From the introductory chapter and this background chapter, it can be seen that, although bioenergy in the UK is already making a considerable contribution to the UK energy supply, many challenges remain. More biomass will be needed in the next 30 years if BECCS is to deliver the negative emissions needed as a part of the UK plans to reduce GHG emissions to net zero by 2050. Although some incentives have been effective in the past at encouraging bioenergy generation, previous incentives to grow PECs in the UK have not succeeded, and the UK is dependent on imported biomass for large scale generation. Efforts to increase woodland creation in the UK have had only limited success, despite the wide range of government grants on offer. Landowners are vital to the future production of biomass, and will have to be persuaded to adopt PECs and woodland creation at large scale, while there will be other demands for their land e.g. food production and habitat restoration. The GHG impact of bioenergy is a controversial topic and the complexity of the argument has the potential to undermine confidence in the sector. BECCS is not yet proven at scale and it is not clear how the removal of CO_2 from the atmosphere will be rewarded financially.

Chapter 3 Literature Review

This chapter provides a critical assessment of literature relevant to the research. It starts by reviewing frequently used approaches to biomass assessments and some of the studies previously carried out for the UK and Y&H. Literature on the use of poultry litter in AD and on-farm combustion is discussed, then previous research into the barriers to, and drivers for, the cultivation of PECs, woodland creation, and sustainable management of existing woodland is analysed. Theories that are widely used to model adoption of innovations and energy transitions are examined to identify a suitable framework for analysing data gathered from stakeholders about adoption of new farming practices. Many land use change scenarios have been designed and assessed as part of proposals for delivering net zero GHG emissions and some of the most recent ones are reviewed here. Some relevant literature on public policy is reviewed before the main gaps in the literature which are to be addressed in this research are summarised.

3.1 Assessment of biomass potential

This section discusses the different approaches that can be made to executing biomass potential assessments and some of their limitations. The aim of the assessment in this research is to understand the energy potential of the biomass arising in Y&H and to identify where there is the potential to use more of what is already produced, or to increase production. The biomass potential assessment methods used in this research are described later in section 4.2.2.

The main reasons for assessing biomass are to either understand the potential of available biomass to contribute to a local, national, or global energy supply, in which case a supply driven assessment will be required, or to understand the potential for biomass to replace another source of energy, such as fossil fuels or nuclear power, using a demand driven assessment (Biomass Energy Europe, 2010). A biomass assessment is often a part of a full assessment of all types of renewable energy needed for the definition of decarbonisation strategies (AECOM, 2011; Slade et al., 2011).

The particular methodology required to assess biomass potential depends on the purpose and audience for an assessment, the level of detail needed, and the amount of data already available (Rosillo-Calle et al., 2007). Because of the wide range of factors impacting on resource availability, a single methodology cannot be defined for all biomass potential assessments (Welfle et al., 2014). However, assessments generally follow the same fundamental processes which are described by Batidzirai (2012), Slade et al. (2010), and Ciria and Barrow (2016) : these are represented in **Figure 3.1**.

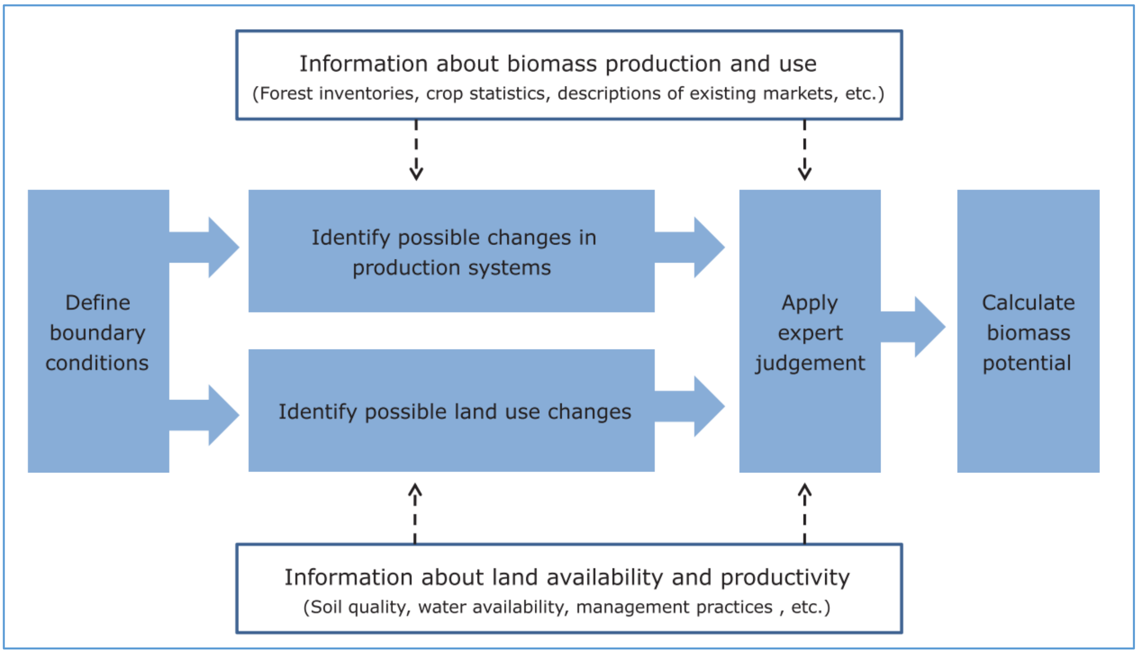

Figure 3.1 Typical workflow for a bioenergy resource potential assessment
From Slade et al. (2010, p4).

Boundary conditions for the assessment include defining the approach required, specifying which categories of biomass are to be assessed, how the resource data are to be gathered and the type of biomass potential to be calculated.

3.1.1 Assessment approaches

The approach to the assessment of biomass can be either *resource* driven or *demand* driven (Biomass Energy Europe, 2010). Resource driven assessments compile an inventory of all available biomasses based on assumptions about land use, resource arisings, and competition for use of the resources. While demand driven assessments are based on the demand for biomass fuels to meet specific target, or to compete with existing energy sources to meet predicted energy demand. An *integrated assessment* will combine both supply and demand-driven approaches (Batidzirai et al., 2012). These different types of assessment produce significantly different results (Slade et al., 2010).

Biomass can be assessed by using field surveys to collect ground data, using remote sensing, using statistics which are already available, or a combination of these approaches, depending on the data available (Rosillo-Calle et al., 2007; Ciria and Barro, 2016) and the scale of the survey i.e. local or national surveys (Esteban et al., 2008). Satellite images are recommended for large scale surveys, and drones for local assessments (Ciria and Barro, 2016).

Statistical analyses are relatively simple, transparent, and low in cost. Spatially explicit analyses using mapping data are better at assessing local or regional availability of data, but are more complex and time consuming to carry out (Batidzirai et al., 2012). Although Batidzirai considers spatial analyses to be less transparent, and more difficult to communicate than statistical analyses (Batidzirai et al., 2012), GIS systems can successfully integrate (APEC, 2008) and display geospatial data (Esteban and Carrasco, 2011; APEC, 2008), e.g. the USA national maps of biomass resource and bioenergy generation (NREL, 2014).

The accuracy of any assessment will depend on the quality of the initial data, and in particular, the physical properties, e.g. the energy content of biomass can vary considerably. Although reference data are available they should be used with caution and if accurate values are needed samples should be tested (Ciria and Barro, 2016). Uncertainty of land availability and crop yields also significantly affect the accuracy of assessments (Esteban et al., 2008). Because methods vary so much between individual studies, comparisons are hard to make (Esteban and Carrasco, 2011), particularly between studies from different countries (APEC, 2008), although efforts have been made to harmonise assessments (Batidzirai et al., 2012; Biomass Energy Europe, 2010).

3.1.2 Types of biomass potential

Definitions of the types of potential estimated vary between authors. Batidzirai defines five types of potential: theoretical, technical, market/economic, ecologically sustainable and implementation (Batidzirai et al., 2012), whereas Slade et al. (2011) uses four levels (see **Table 3.1**).

After defining the boundary conditions for the assessment, information is gathered on biomass availability, land use and productivity, and potential changes in land use and productivity. These are then used to create an inventory or model of potential resource availability. Expert judgement is then required to assess the impact of resource constraints and to reduce the resource potential in a series of steps to calculate the required types of resource potential.

Table 3.1 Definitions of resource potentials
Adapted from Slade et al. (2011).

Type of potential	Definition UKERC
Theoretical potential	The total amount of biomass available each year. This could change if conditions change such as climate or animal populations.
Technical potential	Everything that can be collected from the theoretical potential, subject to technical constraints of topography, technology and the demand for food and housing.
Economic potential	The potential biomass available below a specified price – a highly variable figure.
Realistic potential	The biomass available without negative social or economic impacts. Estimated using factors to reflect realistic maximum rates of use.

The *primary energy* content of the biomass, the energy content before conversion to useable energy such as electricity or heat, is usually quoted for theoretical or technical potentials (Fischer and Schrattenholzer, 2001; Biomass Energy Europe, 2010) and is generally calculated from the lower heating value of the biomass and expressed in terms of Joules (PJ or TJ as appropriate), thousand tonnes of oil equivalent (ktoe) or million tonnes of oil equivalent (Mtoe) (1 ktoe = 41.868 TJ) (BEIS, 2017a, p261). For *economic* or *realistic* potentials researchers select an energy conversion pathway for each type of biomass e.g. assume the conversion to electricity, gas production or use for heat, and calculate the energy that can be delivered: the *secondary energy* content or *bioenergy generation potential* (Welfle et al., 2013), which is usually quoted in terms of GWh or TWh for electricity (1 GWh = 3.6 TJ) (BEIS, 2017a, p. 261).

Biomass potentials are often expressed as a percentage of demand (AEA, 2010; Energy Technologies Institute, 2015) with prediction of demand adding further uncertainty to assessments.

The selection of boundary conditions, the assumptions made in applying constraints, data quality, and assumptions of energy conversion routes can all significantly impact the final assessment. These boundary conditions and assumption need to be clearly stated. Comparing potentials from different studies can be difficult if assumptions are not clearly stated or approaches adopted are inconsistent (Batidzirai et al., 2012). In recent years there has been a tendency to move from producing a single estimate to producing scenarios representing a range of conditions, producing a range of estimates. Studies do not claim to produce definitive results and it is acknowledged that there is no single right answer when assessing biomass potential (Slade et al., 2011).

3.2 Biomass potentials for UK and Y&H

A wide range of estimates for UK biomass potentials has been produced by the many studies carried out. In a review of 14 different resource-focussed assessments of UK bioenergy potential, Slade et al. (2010) found estimates for total primary energy potential for 2030 to be in a range from 400 to 1100 PJ per year (4 to 11 % of UK primary energy supply in 2008). The higher estimates required removal of significant barriers to use. Differences resulted from the different definitions of potentials, the range of biomass types included and the assumptions made on the proportions of resources that can be captured. However, many factors were consistent between the studies, including applying the constraints that: expanding the use of bioenergy should not impact other sectors (such as food production), protected forests should not be used for wood production, deforestation should not result from bioenergy use, and woodfuel production should not compete with timber production.

More recently Welfle et al. (2014) predicted a bioenergy potential by 2050 of 289 to 593 TWh per annum, or up to 44 % of the total UK energy demand, without impacting food production. The maximum potential was estimated when biomass for energy production was prioritised over other land uses and use for heat generation was prioritised over transport fuels and electricity generation. This resulted in a reduction in woodland area which is generally viewed as undesirable. Ricardo Energy & Environment (2017) predicted that UK biomass has the potential to deliver between 8 % and 10 % of the UK demand for energy by 2030.

Figure 3.2 shows the Ricardo Energy and Environment estimates of individual biomass potential by 2030, compared with the energy content of UK sourced bioenergy feedstocks and imported bioenergy feedstocks in 2016. It appears that there is scope to use more of all types of UK biomass except landfill gas, where the long term potential will decline.

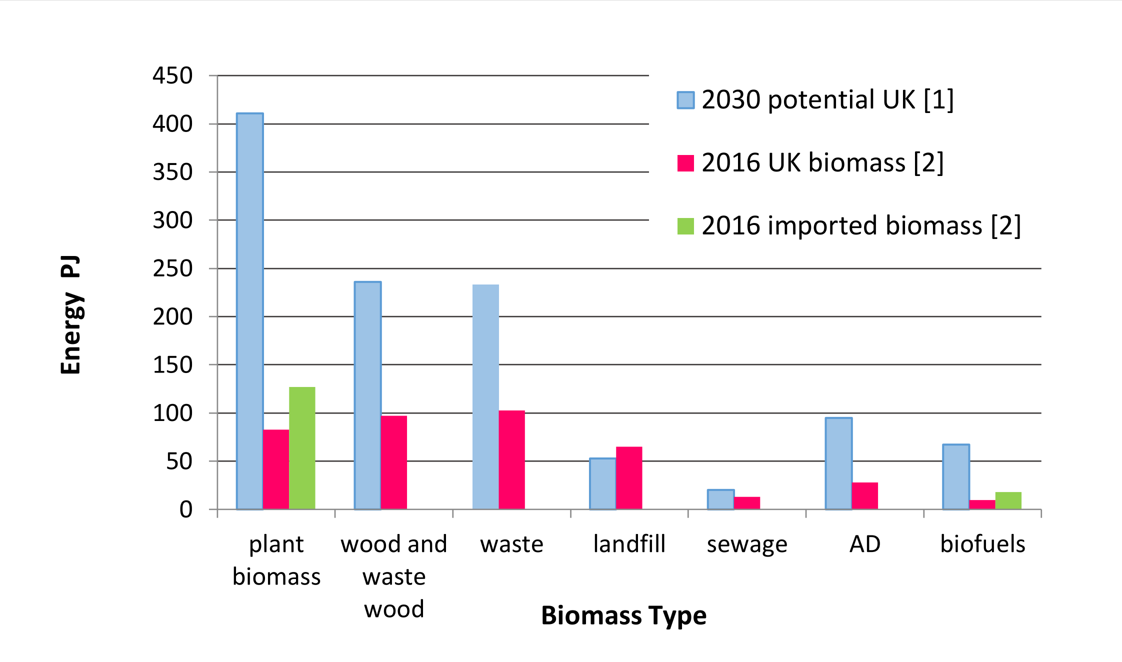

Figure 3.2 Primary biomass potential in 2030 and energy content of UK biomass feedstocks used in 2016
Data from: [1] (Ricardo Energy & Environment, 2017) and [2] (BEIS, 2017a).

The only assessments found for Leeds City and the LCR were a part of the Y&H regional assessment of renewable energy potential by AECOM (2011) carried out in 2010. The report found that the region had the potential to install 1,900 MW of heat and 3,600 MW of electricity generation from renewable energy and that 34 % of this installed capacity could be delivered by bioenergy. However, this assessment in terms of installed capacity is difficult to compare with energy potentials, and the methods used are discussed in detail in Section 4.2.

3.3 The use of poultry litter for bioenergy

The reasons for large scale litter combustion were discussed in section 2.2.1.2.1, and here some literature on smaller scale combustion, and the use of litter in AD is reviewed.

Building on the success of large scale combustion, research was carried out into smaller scale combustion using fluidised bed technology (Abelha et al., 2003; Kelleher et al., 2002) with the potential to deliver benefits to the environment, generate energy and produce valuable ash fertiliser (Lynch et al., 2013). There is evidence of the use of small scale combustion on farms in the UK and Eire (Cooper, 2014; Walsh, 2016) which is suitable for meeting the heat demand for broiler chicken production, which needs significant heating when the chicks are young, but the need diminishes to zero as the chicks grow. There have also been trials in the USA but the practices there are different: litter is not fully removed after each cycle and some poultry sheds have earth or clay floors rather than the concrete floors used in Europe. These differences have caused some teething problems with foreign bodies in the litter and reduced energy content (Farm Manure-to-Energy Initiative, 2016; Chastain, 2019; Kryzanowski, 2017). Many UK farmers heat their poultry sheds using wood pellets in biomass boilers and claim Renewable Heat Incentive (RHI) payments, but some still use gas or kerosene (Ford, 2018).

AD was later identified as another suitable disposal method (Dagnall et al., 2000). AD digestate can also be used as a fertiliser, and as it retains N, P and K it has a better nutrient balance for most farmers than combustion ash (Szogi and Vanotti, 2009). The high levels of ammonia in litter can inhibit methane production and discourage use, but by limiting the proportion of litter by co-digesting with other feedstocks, ammonia can be controlled and methane production enhanced (Kelleher et al., 2002). However, it is possible to process 100 % litter if N stripping is deployed (Agriland, 2018).

Comparing combustion and AD of litter with land-spreading has identified reduced ammonia production and reduced fossil-fuel use as the major environmental benefits, but only a small reduction in GHG emission is delivered if transportation emissions are significant (Williams et al., 2016; Billen et al., 2015). However, as with most life cycle assessments of that period, they are likely to assume that transportation will involve GHG emissions, and in future as transport *is* decarbonised the avoidance of ammonia emissions may become more important.

No evidence has been found of research on the competing demands for poultry litter or on the attitudes to energy use. Many energy potential assessments fail to fully assess the competing demands e.g. Jeswani et al. (2019) assume 100 % of UK turkey, broiler and breeding bird litter is available for energy use while dismissing the use of laying hen litter as unsuitable. Tanczuk et al. (2019) assume 80 % availability in Poland (with no justification).

3.4 Barriers and drivers for the uptake of energy crops

Many studies have been carried out into the cultivation of PECs in the UK, and these have identified some drivers of energy crop uptake, and many barriers. Technical, financial, and behavioural factors have been investigated.

One driver for adoption was the suitability of PECs for poor quality, or marginal land. However, Helliwell (2018) argues that this led to the belief among farmers that they were *only* for marginal land, and many farmers viewed their own farms as too good for energy crops, so felt the crops were irrelevant. When energy crops *were* grown on marginal land, low yields resulted (Helliwell, 2018). Diversification of farm activities and incomes has also been a driver for adoption (Adams et al., 2011; Clifton-Brown et al., 2017) as was the attraction of growing a crop with a positive impact on GHG emissions (Sherrington et al., 2008). The establishment grants (see section 2.6.1) and the contracts offered by the ARBRE project were attractive at the time they were offered (Sherrington et al., 2008). Some growers, especially older farmers, are attracted by a low maintenance crop (Sherrington et al., 2008; Glithero et al., 2013a).

Most research concludes that economic factors were a barrier to energy crop cultivation as well as being a driver. The high initial costs of planting, and the delay before income is generated, being the main barriers to energy crop cultivation (Thornley et al., 2009b; NNFCC, 2012a; Glithero et al., 2013a; Clifton-Brown et al., 2017; Brown et al., 2016). The high prices available for cereal crops in recent years, especially for wheat, have also discouraged farmers from planting energy crops (Sherrington et al., 2008; Clifton-Brown et al., 2017). Planting a perennial crop for 15 to 20 years is a risk for farmers who may be reluctant to change existing farming practices, traditions, and landscape. They may be reluctant to be the first farmer locally to adopt a new technology (Convery et al., 2012), and may be concerned about losing flexibility in their farm strategy (Sherrington and Moran, 2010). Incomes can be hard to predict for novel crops, and some farmers fear that willow will have a negative long term impact on land drains, so farmers expect either incomes to contain a premium to compensate for the risk they are taking, or a grant to be provided (Sherrington et al., 2008). Other frequently cited barriers to the success of SRC and miscanthus adoption were the absence of a consistent UK energy crop policy (Adams and Lindegaard, 2016; Adams et al., 2011; Foxon et al., 2005), and a lack of knowledge among farmers (McCormick and Kåberger, 2007; Convery et al., 2012; White et al., 2013). Negative perceptions of energy crops by the general public can also inhibit uptake of PECs (Mola-Yudego et al., 2014). Limited UK planting and harvesting capacity, technology compatibility, and social resistance related to concerns around long-term land-use change (DECC, 2012), were also cited as barriers.

Technical issues were found with winter harvesting and processing of energy crops in early years (Stenhouse, 1999) and the need for specialist machinery (NNFCC, 2012a; Wilson et al., 2014) has been a barrier to adoption, but McCormick and Kåberger (2007) argue that none of the key barriers are technical.

In research into the attitudes of livestock farmers to energy crops, Wilson (2014) found that they were marginally less likely to grow energy crops than arable farmers, with concerns about the crop suitability for their land being the biggest barrier, and on tenanted farms some landowners restricted the planting of energy crops. Although farmers are interested in reducing carbon emissions and reducing reliance on fossil fuels, they require projects to be economically viable too (Adams et al., 2011; Convery et al., 2012; OECD, 2012). Alexander (2013) suggests that slow uptake of energy crops may just be a time lag in the diffusion of the innovation of growing energy crops, in the same way that oil seed rape diffusion in the 1970s was initially slow before accelerating. However, this is unlikely to be the case as no significant increase in uptake of PECs has been seen since his research.

Although lack of confidence in demand for energy crop biomass and poorly developed supply chains can reduce confidence in growing the crops without stable policy, local heat projects were suggested as possible stable markets (Adams and Lindegaard, 2016; Burgess et al., 2012), especially when the farmers supply the heat rather than selling the biomass to local consumers (Sherrington et al., 2008). Failure of the ARBRE project which planned an energy crop gasification power station in Yorkshire in the 1990s (Piterou et al., 2008; Mawhood et al., 2015; Mitchell and Connor, 2004), reduced the confidence of energy crop growers throughout the UK (Foxon et al., 2005; Adams and Lindegaard, 2016).

Although willow cultivation started earlier in Sweden (with planting subsidies implemented in 1991) than in the UK, it has had a similar history to that in the UK. A period of planting when grants were available was followed by a period of stagnation from 1996, after Sweden joined the EU, and CAP regulations resulted in less favourable incentives (Mola-Yudego et al., 2014). Competition from higher cereal prices was the prime restriction on uptake of willow cultivation (Mola-Yudego and Gonzalez-Olabarria, 2010). Some of the problems encountered in establishing a SRC industry are common across many European countries including Sweden, Germany, Spain and Ireland e.g. lack of lobbying groups and lack of awareness of SRC among farmers, but there are also specific local problems which require specific policy changes (Lindegaard et al., 2016). A new market for miscanthus could be as an AD feedstock (Purdy et al., 2017; Whittaker et al., 2016) but this would require autumn harvesting instead of winter and there is no evidence yet for its use in the UK. Miscanthus is used as animal bedding (Terravesta Equine, 2021) and use as a replacement for wood in composite products and as a construction material has also been proposed (Moll et al., 2020).

Lindegaard (2013), ADAS (2016) and McCalmont (2017) all describe a '*chicken and egg'* problem: farmers will not plant PECs without a market in place, but there will be no investment in generation plant without a supply. McCalmont (2017) recommends top down intervention and policy stability to ensure planting of miscanthus.

Less literature is available on attitudes to growing annual energy crops. Maize had been considered as unsuitable for the UK climate (Thornley et al., 2009b), but more recently new crop varieties have proved popular and growth has accelerated (Curtis, 2018). In general, annual energy crops (such as maize, sugar beet, OSR and wheat) require higher inputs of chemicals and energy than PECs do, but provide greater flexibility to farmers to change crops and take advantage of fluctuations in crop price (Manzone and Calvo, 2016). Annual crops including barley, sunflowers, lucerne, and sorghum incorporated into an arable rotation are all potentially suitable AD feedstocks (Bauer et al., 2010) as is hemp (Finnan and Styles, 2013).

Although grass and grass silage (grass preserved under anaerobic conditions) are recognised AD feedstocks (Brown et al., 2020; Korres et al., 2010; Campbell, 2018), and the technical requirements have been studied (Prade et al., 2019; Meyer-Aurich et al., 2016) no literature was found on the advantages to farmers of growing grass for AD. No literature was found that considers the attitudes of farmers to both annual and perennial energy crops.

3.5 Barriers to woodland creation and management

Much recent forestry research, including some carried out by the FC, is not published in peer reviewed papers, and as such it can be hard to find. Some relevant documents were provided by interviewees who took part in the research for this thesis.

The Forestry Commission (c2006) recognised that barriers to bringing woodfuel to market included: the perception of the grant system as complex, the need for information on management for landowners with different priorities, and a lack of confidence in the woodfuel supply chain. Failure to manage woodland can be either a deliberate practice based on a culture of neglecting woodland (Dandy, 2016), or because of a failure to realise that management is needed (Dandy, 2020). As with energy crops, the lack of confidence in long term fuel contracts could be addressed by vertical supply chain integration of local woodfuel consumption and production (Spinelli et al., 2018).

Although the Government has set targets for planting trees, most of this planting will have to be carried out on privately owned land, and the success of woodland planting schemes depend on the attitudes and objectives of the landowner (Thomas et al., 2015). As there is no compulsion for a landowner to plant (Forestry Commission, 2019a), the creation of woodland must be economically advantageous to the landowner as well as being environmentally beneficial (RFS, 2020). Planting can be complicated further when land is held by tenants (Lawrence and Dandy, 2014; Eves et al., 2014b). A House of Commons review of woodland planting found that although woodland creation in the UK relies on '*a well-functioning grant scheme to incentivise landowners to use their land for forestry*', the Countryside Stewardship Scheme (CSS) was '*not fit for purpose'* and was '*acting as a barrier to greater woodland creation*', being bureaucratic and overly complex (House of Commons, 2017, p. 3).

The incentives for woodland creation not only need to cover the initial cost of planting, but also some, or all, of the income foregone from agricultural activities. Although some grants do now include maintenance payments e.g. *Woodland Carbon Fund*, and the *Woodland Carbon Guarantee* which gives the option of income at five and ten years (Forestry Commission, 2019e), there is still a long period before any income is generated from thinning or felling. The high initial costs of planting trees are supported by grants, but the payback from forestry is over a long term and may still not be economic on poor land (Hardaker, 2018; Forestry Commission, 2017a; Forestry Commission, c2006; Forestry Commission, 2019a).

There is a cultural division between forestry and farming. Some farmers hold negative opinions of adopting forestry on their own land, and the permanent land-use changes required, which they view as bad for both the landscape and food production (Lawrence and Dandy, 2014; Hopkins et al., 2017; Hardaker, 2018; Warren et al., 2016), and they fear that planting trees will reduce the value of their land (RFS, 2020). However, it has been found that farmers who have already invested in other renewable energy crops are the most likely to plant new woodland (Hopkins et al., 2017), and farmers who already own woodlands are twice as likely to plant woods as other other farmers (Eves et al., 2014b). The availability of suitable land for planting is a significant constraint (RFS, 2020), and it is possible that much of the most suitable land has already been used, leaving only poorer less productive land or land that is also suitable for other types of use, such as arable farming (CEH and Rothamsted Research, 2019).

Restrictions on species mix, with priority given to native broadleaved trees, and limits on non-native (generally productive conifers) and honorary native species (e.g. sycamore, sweet chestnut) in new schemes, are deterring planting (RFS, 2020). Other deterrents to woodland creation include the capacity of nurseries to scale up the supply of young trees, and the time taken for new grant schemes to deliver planting (Forestry Commission, 2019a).

3.6 An Analytical framework for landowner decision-making

A theoretical framework can help to make sense of large amounts of data, can help in the design of research, and can help in the comparison of data gathered by different studies (Sovacool and Hess, 2017; Casanave and Li, 2015). Theories, models and frameworks to explain the adoption of technological change have been developed in a wide range of disciplines including psychology, anthropology, business and management studies, sociology, and urban studies (Sovacool and Hess, 2017). Most research published on the production and use of biomass does not use an analytical framework, but in the wider fields of low carbon energy adoption, farm diversification, and adoption of innovative agricultural practices, some studies have used a framework. The theories most widely used for analysis in these fields include diffusion of innovation, behavioural change theories, and socio-technical transitions. These three options are discussed in the following sections. The selection of the most appropriate framework for analysing the data in this research is covered in section 4.3.1 of the methods chapter.

3.6.1 Diffusion of Innovation (DOI) theory

The research into diffusion of innovations began in the early 20th century with Gabriel Tarde who considered imitation (diffusion) of innovations as changes to human behaviour (Rogers, 2003). As long ago as 1911 Joseph Schumpeter described an economically successful technical change as being made up of three phases: invention, innovation (or commercialisation of the invention), and finally diffusion (adoption or imitation) of the change (Soderholm and Klaassen, 2007; Braunerhjelm and Svensson, 2010). The study of diffusion of innovations was carried out independently in a large number of fields, such as rural sociology, which included the work of Ryan and Gross (1950) on the adoption of new crops in the US. While studying the diffusion of agricultural innovations, Everett Rogers proposed a unified theory that could apply across a wide range of research fields (Rogers, 2003).

Rogers' model of DOI has been used in the study of the uptake of a wide range of technological, medical, educational, and social innovations which can have advantages for adopters. It has been used to define an analytical framework for studying energy crop adoption in the USA (White et al., 2009), cultivation of biofuel crops in Scotland (Warren et al., 2016) and the uptake of low-carbon energy including: solar power (Pathania et al., 2017; Simpson and Clifton, 2017), wind power (Friebe et al., 2014; Soderholm and Klaassen, 2007), heat pumps (Owen et al., 2013), wood pellet use (Sopha et al., 2011) and retrofitting of domestic energy technology (Owen and Mitchell, 2015).

Rogers defines diffusion as *'the process in which an innovation is communicated through certain channels over time among the members of a social system'* (Rogers, 2003, p5). The innovation could be '*an idea, practice or object that is perceived as new by an individual or unit of adoption'* (p12), so any change to current practices or technology could be considered as an innovation. He argues that the rate of adoption depends on the five factors of: relative advantage, compatibility, complexity, trialability, and observability of the innovation. White et al. (2009) add a sixth factor: degree of risk. Communication channels in Rogers' model include a variety of social processes: mass media communications play a part but personal communications are more effective, especially when communication is between homophilous participants (those with similar interests, attitudes, backgrounds and status (Rogers, 2003)).

Time is an important part of the Rogers model with five steps in decision-making being: knowledge (becoming aware of the innovation), persuasion (forming an opinion of the innovation), making the decision, implementation of the innovation, and confirmation (where an adopter seeks reassurance that they have made the right decision). Discontinuance can follow where an innovation is abandoned by a dissatisfied adopter or is superseded by a newer innovation (Rogers, 2003). An overview of the decision making process can be found in Rogers (2003, p. 170), and on line in in Figure 1 of Marcial (2015).

Rogers models diffusion using an s-curve, with a slow initial uptake followed by accelerated adoption, and finally a levelling off as maximum adoption is approached. Adopters can be categorised as *innovators, early adopters, early majority, late majority,* or *laggards* depending on their willingness to innovate and their relative time of adoption (p 281). The social system is defined as '*a set of interrelated units that are engaged in joint problem solving to accomplish a common goal'* (p23). There will generally be a communication network within the social system, which will be well developed if the members are homophilous. Within the social system members will be influenced by norms of behaviour, by opinion leaders, and change agents.

Innovation studies, including Rogers' DOI, have been criticised for having a pro-innovation bias (Botha and Atkins, 2005, p. 107; Sveiby et al., 2009; Karch et al., 2016; Rogers, 2003), which can affect both the researcher and the respondents from whom data is gathered, and can lead to lack of attention on unintended consequences of innovations (Sveiby et al., 2009). Karch argues that the pro-innovation bias of DOI theory means that it is more often used for studying successful diffusions than for unsuccessful innovations, where it can be harder to find evidence, and as fewer failures to diffuse are studied, the theory has limited scope for identifying the factors responsible for success or failure of adoption.

Rogers' DOI has also been criticised for having a single perspective (the adopter of the innovation), and although it is suitable for studying adoption by individuals it is not suited to the muddled and overlapping phases of adoption in a large organisation (Wolfe, 1994). Charters and Pellegrin (1973) argue that the steps of innovation diffusion do not apply well to innovations that are not well defined, or are developed within an organisation rather than being imposed from outside.

3.6.2 Behavioural change theories

Behavioural change theories can also be used to understand why new practices or behaviours are adopted and they have been used to understand barriers to, and drivers for, change in agricultural practice, as well as a wide range of consumer, health, and lifestyle decisions.

The *Theory of Reasoned Action* (TRA or TORA) defined by Fishbein and Ajzen (2009) was later expanded into the *Theory of Planned Behaviour* (TPB) (Ajzen, 1991). The TPB proposes that human behaviour and propensity to change are dependent on three types of belief.

Behavioural beliefs, about the consequences of the behaviour, result in positive or negative attitudes to the behaviour. Normative beliefs, about what others expect of them, result in social pressures. Control beliefs, about the factors which may improve or hinder the behaviour, lead to ideas about how easily the behaviour can be performed. The combination of these attitudes, social pressures, and perceptions of ease of adoption, result in an intention, which together with the actual ease of action, can predict the likelihood of a particular behaviour being adopted (Ajzen and Fishbein, 2000). The TRA has been used to assess the uptake of energy crops (Sherrington et al., 2008), the willingness of farmers to adopt environmental management (Mills et al., 2017), and the attitudes of Scottish landowners to woodland creation (Thomas et al., 2015).

A further development of TRA and TPB is the *Technology Acceptance Model* (TAM) (Davis, 1989; Davis et al., 1989) which models the adoption of information technology as being dependent on the perceived usefulness and ease of use of the technology. These key factors are similar to the DOI characteristics of relative advantage and complexity and thus TAM has been considered to be a subset of DOI (Moore and Benbasat, 1991; Karahanna et al., 1999).

The *Unified Theory of Acceptance Use of Technology* (UTAUT), used predominantly in management science for the study of workplace acceptance of technology, combines TAM, TPB and DOI (Sovacool and Hess, 2017).

3.6.3 Socio-technical transitions

Socio-technical systems are defined by Rip and Kemp (1998), cited in Smith et al. (2005), as

> "*relatively stable configurations of institutions, techniques and artefacts, as well as rules, practices and networks that determine the 'normal' development and use of technologies".*

Geels (2004) defines socio-technical systems as *"the linkages between elements necessary to fulfil societal functions (e.g. transport, communication, nutrition)*" which cover the production, diffusion and use of technology. Radical changes to these stable regimes, such as the adoption of a new energy generation technology, are likely to involve a complex series off inter-related events (Smith et al., 2005) involving a *'constellation of actors and networks'* (Silveira and Johnson, 2016).

Socio-technical transitions are the most commonly used conceptual framework for explaining socio-technical change (Sovacool and Hess, 2017), and have been used to study many industry scale transitions including: low carbon transitions of urban infrastructure (Bulkeley et al., 2014; Hodson and Marvin, 2010), bioenergy adoption (De Laurentis, 2015; Silveira and Johnson, 2016), electricity transitions (Geels et al., 2016), city infrastructure (Eames et al., 2013), and district heating in the UK (Bush et al., 2016).

Socio-technical transitions theory, also known as the *'Multilevel Perspective'* (MLP) on socio-technical transitions and innovation (Geels and Schot, 2007), models change as occurring through actions and interactions at three nested levels: niche, regime, and landscape. Niches at the lowest level in the model are where radical innovations occur, and are developed, by groups or networks of dedicated actors, protected from the pressures of the regime (Geels, 2002). Innovations will generally have low performance and be unprofitable initially, but can be nurtured at the niche level (Geels and Schot, 2007) with incentives and grants. Socio-technical regimes are the sets of practices and rules within an engineering community, and they result in stability because they guide innovative activity towards incremental improvements along common trajectories (Geels, 2002). Socio-technical landscapes are the external environments such as political, macro-economic and cultural backgrounds, which are outwith the influence of actors working at the niche or regime level. Any changes at the landscape level take place very slowly (Geels and Schot, 2007).

The MLP models transitions as occurring when innovations being practiced and developed at the niche level gain momentum through improved performance and backing from powerful groups. Pressure from the landscape level can put pressure on the regime to change, and opportunities can become available for niche innovations to challenge the incumbent regime (Geels and Schot, 2007). The success of a new technology is dependent on processes within the niche, the existing regime and the landscape (Geels, 2002).

There have been may critiques of MLP. Sovacool and Hess (2017) argue that its widespread use is a result of the emphasis on modelling interactions between the three levels of the model which allow non-linear changes to be studied, and the incorporation of learning and co-evolution. However, it has been criticised for a lack of focus on the agency of individual actors (Smith et al., 2005; Lawhon and Murphy, 2010; Geels, 2011), focussing only on national scale changes (Smith et al., 2010), ignoring the impact of power relationships, and focusing on elite actors only (Smith et al., 2005). Geels (2011) describes socio-technical transitions as being 'about relatively rare, long-term macro-changes' and in interview with Sovacool (Sovacool and Hess, 2017) he contrasts two types of diffusion models:

> *'Within the realm of diffusion, you have two very different families of concepts. One is the family of adoption models, which focus on purchase decisions by consumers and households. Another family is sociotechnical models, which look at*

the broader system and aspects such as system builders, co-construction and societal embedding of new technologies.'

As such, socio technical transitions theories seem appropriate for studying the macro-scale changes in whole systems transitions, but less suitable for studying changes at a smaller scale involving the decision making of individuals. The selection of a framework is discussed in section 4.3.1.

3.7 Land-use change

3.7.1 Land-use change scenarios

Many different land-use change scenarios have been designed which could deliver GHG emissions reductions in the UK (Allen and Hammond, 2019; ADAS, 2016; CCC, 2020a; CEH and Rothamsted Research, 2019). These have different levels of ambition and different strategies, and as time has passed these scenarios have become more ambitious as the targets for emissions reduction have increased. The land-use changes included in the scenarios vary but include: tree planting, the cultivation of biomass for BECCS, a reduction in the land area used for grazing ruminant livestock, the adoption of agroforestry, increased areas of hedgerows, peatland restoration, and increased areas of settlements to accommodate population growth. Three sources of recent models, which aim to be both ambitious and realistic, are discussed below.

The scenarios described by the CCC (2019) and their associated land-use changes (CCC, 2020a) are of particular interest. These are based on earlier land use modelling (CEH and Rothamsted Research, 2019; Thomson et al., 2017; CCC, 2018b) and have been designed to be realistic scenarios, achievable with current technology, and consistent with expected consumer behaviour. They are expected to influence government planning and decision making. The three scenarios they describe are:

- ***Core*** which would deliver reductions of 77 % from 1990 levels and is based on the UK Government's fifth carbon budget (Priestley, 2019) which originally aimed for an 80 % GHG reduction,
- ***Further Ambition*** which would deliver 96 % reduction by 2050, and
- ***Speculative*** which would deliver more than 100 % emissions reduction.

To achieve net zero GHG reduction all the *Further Ambition* scenario would have to be delivered together with some of the measures in the *Speculative* scenario.

Five CEH Rothamsted (2019) scenarios are based on combinations of measures with three levels of ambition: low (or business as usual), medium and high. The ***Medium Ambition*** scenario measures are all currently-available actions and technologies e.g. precision farming agroforestry, afforestation, crop breeding, and manure management; and could deliver the fifth carbon budget targets. The ***High Ambition*** measures include increased use of the *Medium Ambition* measures, plus emerging technologies, and measures which are currently not financially viable, or are not acceptable to consumers e.g. indoor horticulture, synthetic meat production and production of insect-derived protein.

The Energy Systems Catapult (ESC) (2020) have carried out further economic analysis on the CCC scenarios and have defined two possible pathways for delivery: ***Clockwork*** which assumes centralised policies with significant government intervention delivering significant PEC production and CCS; and ***Patchwork,*** a decentralised model which relies more on market forces and assumes that energy crops will not receive market support, but woodland creation will be popular with landowners.

The key components of the CCC scenarios, the CEH levels of ambition and the ESC pathways are presented in **Table 3.2**. The tree planting targets in the scenarios generally lie between the current UK Government target of 30 kha per annum and the Woodland Trust target of 48 kha per annum, but far below the Friends of the Earth target of 100 kha per annum (see section 2.6.3). The type of energy crops planted vary between the scenarios, with CEH Rothamsted including SRF (32.5 %), as well as the more usual SRC (32.5 %), and miscanthus (35 %). The assumptions about the type of land to be used for each type of planting vary too. CCC (2020a) assumes that miscanthus will be planted on cropland, SRC and SRF on rough grazing, and trees will be planted on a mixture of permanent pasture and rough grazing. CEH Rothamsted *Medium Ambition* measures assume commercial afforestation of rough and improved pasture with only agroforestry on crop land, but the high ambition scenario avoids planting on peat and assumes extensive planting on rough and improved grass land, plus some cropland. It assumes miscanthus crops would be planted on existing cropland and SRC/SRF would be planted on grassland. The type of land preferred for planting will have a huge impact on the location of suitable land and the feasibility of hitting the planting targets.

Table 3.2 Key components of land-use change scenarios
Data from CCC (2019), CEH Rothamsted (2019), and Energy Systems Catapult (2020).

	GHG reduction from 1990	Annual Tree planting	Total new wood-land by 2050	Area of PECS by 2050	Agroforestry	Peatland restoration	Hedges
		kha	kha	kha			
CCC *Core*	87 %	27	Increase to 15 %			Not included	Not included
CCC *Further Ambition*	96 %	30	900	700	10 % of arable and pasture	25 % of lowland peat, 50 % of upland peat	40 % increase
CCC *Speculative*	Over 100 %	50	1,500	1,200	10 % of arable and pasture	50 % of lowland peat, 75 % of upland peat	40 % increase
CEH *Medium ambition*	n/a	31	930	700 (miscanthus, SRC and SRF)	5 % of arable and pasture	25 % of intensively managed lowland peat, 50 % of Unimproved Grassland & 25 % of forest on peat	30 % increase to 168,200 ha
CEH *High ambition*	n/a	50	1,500	1,200 (miscanthus, SRC & SRF)	10 % of arable and pasture	50 % of intensively managed lowland peat, 75 % of unimproved Grassland & 50 % of forest on peat	increase to 181, 300 ha
ESC *Clockwork*	100 %	30	900	1,400	Not included	Not included	Not included
ESC *Patchwork*	100 %	50	1,500	Low unspecified	Not included	Not included	Not included

Some authors assess the suitability of land by using agricultural land grades e.g. Lovett et al. (2009), Lovett et al. (2014), ADAS (2016) and Thornley et al. (2009a). However, the grading of land is not the same in all the home countries e.g. in England and Wales agricultural land is graded from one (excellent quality) to five (very poor quality) with three subdivisions within grade three (MAFF, 1988), the approach in NI is similar (Wright et al., 2020), but in Scotland soil graded from one to seven with further subdivisions giving thirteen classifications in total (The Macaulay Land Use Research Institute, 2010). Models such those used by the CCC (2020a) and CEH and Rothamsted Research (2019) classify land as arable, temporary pasture, permanent pasture and rough grazing, as reported by DEFRA (2019e), which allows a single approach across the UK and allows the *change of use* to be modelled not just the area of planting.

Since these scenarios were reviewed, the CCC announced four more scenarios in December 2020 as a part of the sixth carbon budget. These include their most ambitions scenario to date, the *Tailwind Scenario* which reaches net zero in the mid-2040s and includes planting 1.4 Mha of energy crops by 2050 and 70 kha of woodland creation per annum by 2035 (CCC, 2020e; CCC, 2020c; CCC, 2020b) . The *Balanced Scenario* is their new central scenario, which has the same energy crop targets as the *Further Ambition* scenario, but it targets 18 % woodland cover by 2050 with annual woodland creation rising to 50 kha per annum between 2035 and 2050, with conifers outnumbering broadleaves by 2:1, and increased woodland management to boost woodfuel production

3.8 Policies and policy making

This section contains a review of some of the relevant research on the economics of climate change; the formulation, delivery, categorisation, and assessment of public policies; and the policies which have been proposed to promote PEC and woodland planting.

3.8.1 The economic view of climate change

Most economic analyses of climate change are based on the theories of externalities and public goods (Stern, 2007, p.27). Externalities are the side effects of the production or consumption of goods. These effects can be positive or negative: generating either external benefits or external costs respectively (Sloman and Garratt, 2013, p. 149). In these models GHG emissions are the negative external costs of a number of activities, including fossil fuel consumption, agricultural activity, and land-use change, and are borne by society as a whole. In a free market there is no compulsion for the producer of pollutants to pay for their negative costs to the environment, and a market failure results. This failure could be corrected by governments taking action themselves, by governments persuading producers to behave differently or by using a number of policy instruments including taxes, subsidies, and legislation (Sloman and Garratt, 2013, p. 157). The negative externality of a process can be paid for directly by a consumer (Engel et al., 2008) in a Coasian agreement (Sloman and Garratt, 2013). For example a water company may pay farmers to reduce water contamination within a catchment area (Engel et al., 2008; DEFRA, 2013b). Forest Carbon is an example of a company which has been set up to allow polluters to pay indirectly for GHG emission by funding tree planting under certified schemes (Forest Carbon, 2020).

Stern (2007, p.1) views climate change as the '*greatest example of market failure that we have ever seen*'. He proposes a range of policy responses including taxes based on the emissions (a Pigovian tax based on the cost of the damage of the externality which can not be internlised in any other way) (Sloman and Garratt, 2013), thus creating a price for carbon, which together with carbon emissions targets, would create a market where emissions could be traded and would ensure that polluters pay the full social costs of their actions. The pricing of emissions, putting a value on the CO_2, could provide a value to the carbon sequestered by trees and the carbon stored by CCS, thus encouraging the delivery of these services.

Carbon pricing alone is not expected to be enough to deliver climate change mitigation and significant government intervention will be needed (Hanemann, 2010; Hepburn, 2010; Stern, 2007). Government investment is specifically needed in research and development in green technology as this will not be delivered by market mechanisms (Mazzucato, 2015; Stern, 2007). Policies will be needed to promote behavioural changes, such as lowering consumption of red meat and switching to electric vehicles. It is particularly important that governments should signal their policy intentions clearly to create certainty (Stern, 2007; Mazzucato, 2015) and policies should be fair, predictable, not subject to retrospective changes, and should allocate risk to the parties in the best position to bear them (Hepburn, 2010).

Hepburn (2010) describes a '*spectrum of policy interventions'* with increasing levels of government intervention. These range from a free market with no intervention, through increasing information delivery, persuasion (nudging), carbon pricing, increasing degrees of regulation, direct government intervention in individual projects, and nationalised government delivery of change. He argues that policies from the more interventionist end of the scale will be needed to mitigate climate change.

A public good is defined as *'a good or service that has the features of non-rivalry and non-excludability and as a result would not be provided by the free market'*, where a non-rivalrous good is one which can be enjoyed by any number of consumers without reducing the amount available, and a non-excludable good is one where the consumption of the good cannot be limited by its producers (Sloman and Garratt, 2013, p. 151). Public goods are socially desirable but unprofitable for producers. Commonly quoted examples include street lighting and flood barriers. They are subject to the problem of free-riders: consumers of a public good who are unwilling to pay for the good, instead relying on others to provide it (Sloman and Garratt, 2013, p.149). Climate change mitigation is clearly a public good from which society will benefit, but in a free market there is no incentive for delivery, and government intervention is required to ensure delivery.

3.8.2 Public policies

Cairney (2012) provides two useful definitions of public policy. Firstly

" ' ***policy*** *is a general term used to describe a formal decision or plan of action adopted by an actor … to achieve a particular goal …* ***Public policy*** *is a more specific term applied to a formal decision or plan of action that has been taken by, or has involved, a state organisation.' (Richards and Smith, 2002:1)"* (p25),

and secondly, that public policy is *'the whole sum of government action from signals of intent to the final outcomes'* (p5).

The UK, like most western countries, is a mixed market economy in which the Government provides public services and makes some additional economic decisions to regulate the market, particularly when the free market has failed to deliver desired outcomes for the country (Sloman and Garratt, 2013). It follows the *Regulatory State Paradigm* (RSP), where the Government builds a framework of policies which aim to steer behaviour in the desired direction, then relies on the market to deliver the desired outcomes within the framework of regulation (Mitchell, 2008).

Cairney (2012, p. 26) provides a list of the most common types of public policy which includes: public expenditure, economic penalties (e.g. taxes or charges for services), economic incentives including subsidies and tax breaks, legislation or formal regulation with legal penalties, voluntary regulations, public education, provision of resources or services to change behaviour, funding influencing organisations, funding research, and organisational change in national or local government (e.g. establishing new departments).

Some voluntary delivery of sequestration will be delivered by charities, individuals, and corporations (through corporate social responsibility, or environmental, social, and governance activities), but this unlikely to be sufficient. While growing energy crops or planting trees on a large scale remains financially attractive, public policies will be needed to steer UK landowners into delivering these public goods.

3.8.3 Formulating and delivering public policy

3.8.3.1 The policy window

Kingdon (1995) describes how policy making occurs in an environment where the three streams of problems, policies, and politics, flow independently through and around government. In this Multiple Stream Framework (MSF), agendas are set by problems or politics, and solutions are generated in the policy stream. *Policy entrepreneurs* invest their resources in developing their pet problems or proposals, lobbying for attention, and then connecting problems to solutions and politics (Kingdon, 1995, p.20). Major policy changes are made when the three streams become linked, creating the conditions for a *policy window* during which policies can be selected and implemented. Policy windows can be opened either by the appearance of compelling problems, or by events in the political stream. Interest groups (activists and industry bodies) and public opinion (influenced by the mass media) are important influencers of the policy agenda, with public opinion often opposing change. Experts generally select the appropriate policy solutions. Kingdon's model was developed for the USA but is widely used in comparative policy studies of other countries (Béland and Howlett, 2016), and for analysing the policy making of the EU (Ackrill et al., 2013).

Another model of policy development, The Advocative Coalition Framework (ACF), developed by Sabatier and Jenkins-Smith (1993) explains a complex policymaking environment which contains multiple layers of government, operates despite uncertainty and ambiguity, may take many years to develop policies, and can process in very different ways depending on the stimulus for policy formulation (Cairney, 2013b). A third model, The Punctuated Equilibrium Theory, (Baumgartner and Jones, 1993) explains how long periods of stable policy making can be punctuated by short periods of intense instability and change: often reacting to heightened public attention on an issue (Cairney, 2013a).

The MSF, ACF and PET, are all used in policy analysis (either alone or in combination for each specific study) (Bandelow et al., 2019; Wood and Tenbensel, 2018), and focus on the convoluted political actions required to reach the point where policies can be designed, approved, and implemented. However, this is not the focus of this research which is concerned with the identification of policy options to tackle well recognised issues. Kingdon describes '*an idea whose time has come*' as one which can be recognised by *'sustained and marked changed in public opinion',* and the '*mobilisation of people with intensely held preferences and bandwagons on to which politicians of all persuasions can climb'* (Kingdon, 1995, p. 1). The focus of this research is on the formulation of policy during a policy window.

3.8.3.2 Designing policies and policy mixes

The development of policies is frequently described as taking place in a development cycle, using terms similar to those of any project delivery. For example Kingdon (1995) describes the four steps of: setting the agenda, specifying the policy options, making an authoritative choice of option (e.g. a vote on legislation) and implementing. Cairney (2012, p.33) adds two further steps (evaluating policy success after implementation, and finally policy maintenance, succession or termination), and highlights the factors which affect the success of implementation which include having clear objectives, good solutions and having the necessary resources of money and staff available throughout the policy cycle (p. 35).

The steps of policy design are also similar to those described for a prospective policy analysis, which Dunn (2014) describes as synthesising information to identify policy alternatives which can be used as the basis for making policy decisions. The eight step process of a simple policy analysis are described by Bardach (2012), and Collins (2005). The steps are: define the problem, assemble some evidence, construct the alternatives, select the assessment criteria, project the outcomes, confront the trade-offs, decide, and tell your story (Bardach and Patashnik, 2019). Cairney favours a five-step approach of: define a problem, identify technically and politically feasible solutions, use value-based criteria and political goals to compare the solutions, predict the outcomes and finally make a recommendation.

Howlett (Howlett, 2009) describes three levels of policy design: the highest level defines the general type of policy goal (such as environmental protection) and the preferred policy tools (such as coercive instruments or persuasion). The middle, or programme level, defines the objectives to be met and the choice of instrument types (such as taxes), and the lowest level specifies the specific policy settings and the calibrations (such as the level of subsidy) required. It is the middle level which is of most interest in this research: focusing on the choice of instrument but there will also be some consideration of the factors influencing the settings.

Policies may not always deliver the anticipated changes: their inadvertent effects could be a *null effect* with no impact at all on the problem being targeted, a *side effect* that is not detrimental, or they may deliver a *perverse* (or rebound or boomerang) effect which is the opposite of the intended effect (Vedung, 2017). Policies chosen should be the right tool for the job, as financially efficient as possible, and morally acceptable (Hood and Margetts, 2007).

Any policy solution to a complex problem is likely to made up of a portfolio, or mix, of policy instruments using '*different kinds of motivations'* (Howlett, 2018) and constructed using a tool kit of policies (Howlett et al., 2015). A policy mix will be designed for a specific time, location, government level and policy field (Rogge and Reichardt, 2016). The levels of governance can include supra-national, national or local (Nykamp, 2020). The characteristics of a political system, such as national policy style and the organisational setting of the decision maker, are likely to influence the choice of policies (Linder and Peters, 1989).

There are many requirements of a policy mix. The component instruments should be mutually reinforcing, but interactions among multiple policies are often not well understood or coordinated, and this can result in policies undermining each other, becoming redundant or reducing their effectiveness and efficiency overall (Hood, 2011, p. 37). Care must be taken to avoid over and under design, to ensure that each instrument complements the others and that the mix is able to be adapted over time to accommodate new requirements (Howlett and Del Rio, 2015). Policies within a mix are often assessed for consistency, coherence and congruence (Howlett and Rayner, 2013) and legitimacy is needed for policy to be supported on implementation (Salazar-Morales, 2018). Merril and White (2018) stress the importance of identifying a policy target (the actor(s) at whom the policy is directed).

Policies can be completely new, but more commonly a new instrument is layered on top of the existing mix, or a *patch* is applied by changing one or more of the instruments, and in time a complex arrangement of instruments and policies evolves (Howlett and Rayner, 2013). It is often quicker to reform an existing policy rather that implement a new one (Shapiro, 2018).

3.8.4 Categorising public policies

As many policy analyses are based on policy taxonomy it is useful to consider the many ways in which public policies can be categorised.

Lowi (1972) developed a policy taxonomy based on the likelihood of coercion being used, and whether the coercion was applied to individuals or to whole environments: resulting in four types of policy: regulatory, distributive, redistributive and constituent. Policy makers generally prefer to '*move up the spectrum of coercion'* to achieve their goals with the minimum level of coercion necessary (Howlett and Rayner, 2013). Lowi's model was developed into a continuum of policy instruments (the Doern continuum), based on levels of increasing coercion ranging from exhortation, through financial and regulation instruments, to public enterprise (Howlett, 2011, p.49). Hepburn's (2010) spectrum of degrees of intervention (running from no intervention to direct intervention (see section 3.8.1)), can also be used to categorise policies.

Balch (1980) categorised polices that could change behaviour in individuals into one of four types: informing, facilitating, requiring with penalties, and incentives. By the 1980s Christopher Hood (1983, pp. 5 - 7) had developed the *NATO taxonomy* for policy tools based on the four kinds of resource available to government: *Nodality* (the way in which governments communicate from a node within an information or social network), *Authority* *(using legal or official power), Treasure (financial or other tradable resources) and Organisation (the possession of skilled people, buildings, materials and tools needed to act directly).* Howlett (2011) further developed Hood's model using the four resource categories of: *information, authority, treasure and organisation.*

The minimalist approach of using only the three policy categories of economic means (or carrots), regulations (sticks) and information (sermons), is strongly promoted by Vedung (1998), who argues that there is no need for *organisations* being a fourth type of instrument as they are a prerequisite of all policy delivery.

More recently the importance of public policy to change public behaviour has been recognised (Dolan et al., 2012; Dolan et al., 2010; Moseley and Valatin, 2014). The use of *nudges* developed from behavioural economics by Halpern (2004) and executed by the UK Government *Behavioural Insights Team*, have been identified as effective policy instrument (Howlett, 2018; Howlett and Mukherjee, 2018), and used in policy analysis of forest economics (Valatin et al., 2016; Moseley and Valatin, 2014; Moseley et al., 2014). However, John (2013), in considering nudges as policy tools, argues that the success of all policies is dependent on how they are communicated and as such nudge policies could be considered as informational.

These different taxonomies are used to define a single framework for policy analysis (see section 4.4.3).

3.8.5 Policies proposed for PEC cultivation and woodland creation

Many documents have been produced by advocates for farming and forestry industries, impartial researchers, and government bodies, all proposing their solutions to overcoming the barriers to PEC cultivation and woodland creation. Some documents cover all types of land-use change and so cover both or both PECs and woodland (CLA, 2019; Energy Systems Catapult, 2020; NFU, 2019; Whitaker, 2018; CCC, 2020a; Confor, 2017), one focusses specifically on promoting energy crops (Lindegaard, 2013), and others are focussed on woodland (Forestry Commission, 2019a; Woodland Trust, 2020a; CLA, 2009; Soil Association and Woodland Trust, 2018; Confor, 2019a).

These documents were analysed to create the set of candidate policies to be assessed for their desirability, feasibility, and effectiveness in overcoming the barriers, and potential for causing undesirable interactions and unintended consequences. A full list of policies identified can be found in **Table 7.4**, and they are discussed in depth in section 7.4.

3.9 Gaps in the literature

Having reviewed the relevant literature it can be concluded that there is no up to date assessment of the biomass potential of Leeds, or the Y&H region, and there is no literature on the level of use of poultry litter for bioenergy in the UK, or on competing demands for its use. Although there have been studies on the failure of PECs to be adopted by UK farmers, none have investigated the rapid uptake of annual energy crops while PEC adoption has stagnated. The reasons why the UK has failed to meet woodland creation and management targets have been widely discussed in grey literature, but no studies have considered both the planting of energy crops and the creation of woodland, their possible common issues, or whether they could compete for the same land.

Although many organisations have proposed policies that could deliver woodland creation or PEC cultivation, there has been little published on assessments of how these policies could be implemented together to deliver the desired land-use change in the face of competition for land from food production, expansion of settlements, and restoration of valuable habitats.

The following methods chapter addresses how these gaps in the literature can be filled.

Chapter 4 Methods

This chapter starts with an overview of the research methods and how they were used to meet the overall goal of the research: to assess the prospects for increasing the UK production of bioenergy feedstocks needed as a part of the drive to reduce net UK GHG emissions to zero by 2050. The research methods and designs are then described in detail for each of the main activities. The theories behind some of these methods have already been discussed in the literature review.

4.1 Overview of methods

To understand the prospects for increasing UK production of feedstocks for bioenergy, the three research questions defined in section 1.6 must be answered. A mixed methods approach was taken: performing a biomass assessment, stakeholder interviews and then policy analysis. **Figure 4.1** shows an overview of the main methods used and the outputs from each step of research.

Research started using the Y&H region as a case study, with a particular focus on the city of Leeds. To answering the first research question: '*Which types of biomass have potential for increased production or use in Yorkshire and Humberside?*' an appropriate biomass assessment method was selected, adapted, and expanded to meet the requirements of this particular study, then used to assess the potential for the individual local authority areas of the Y&H region (e.g. the City of Leeds), and for the Y&H region as a whole. The *actual* biomass production and use in the region were estimated from statistical data and compared with the potential.

This comparison identified that there was potential in Y&H to increase production of energy crops and woodfuel, and to use more poultry litter for energy. The next step of research was to understand why energy crops were not being grown, why woodland creation and management targets were not being hit, and why poultry litter was not being fully utilised for energy generation. To answer research question two, '*What are the barriers to, and drivers for, the greater production and use of biomass for energy production?*' semi-structured interviews were held with a range of stakeholders including landowners, farmers, foresters, and land advisors. Rogers' Theory of Diffusion of Innovation was used as a framework to understand the decisions made by farmers and landowners when they considered planting PECS, creating woodland, managing woodland, or using poultry litter for energy. As well as identifying barriers and drivers, the interviews also captured suggestions of how some of these barriers could be overcome.

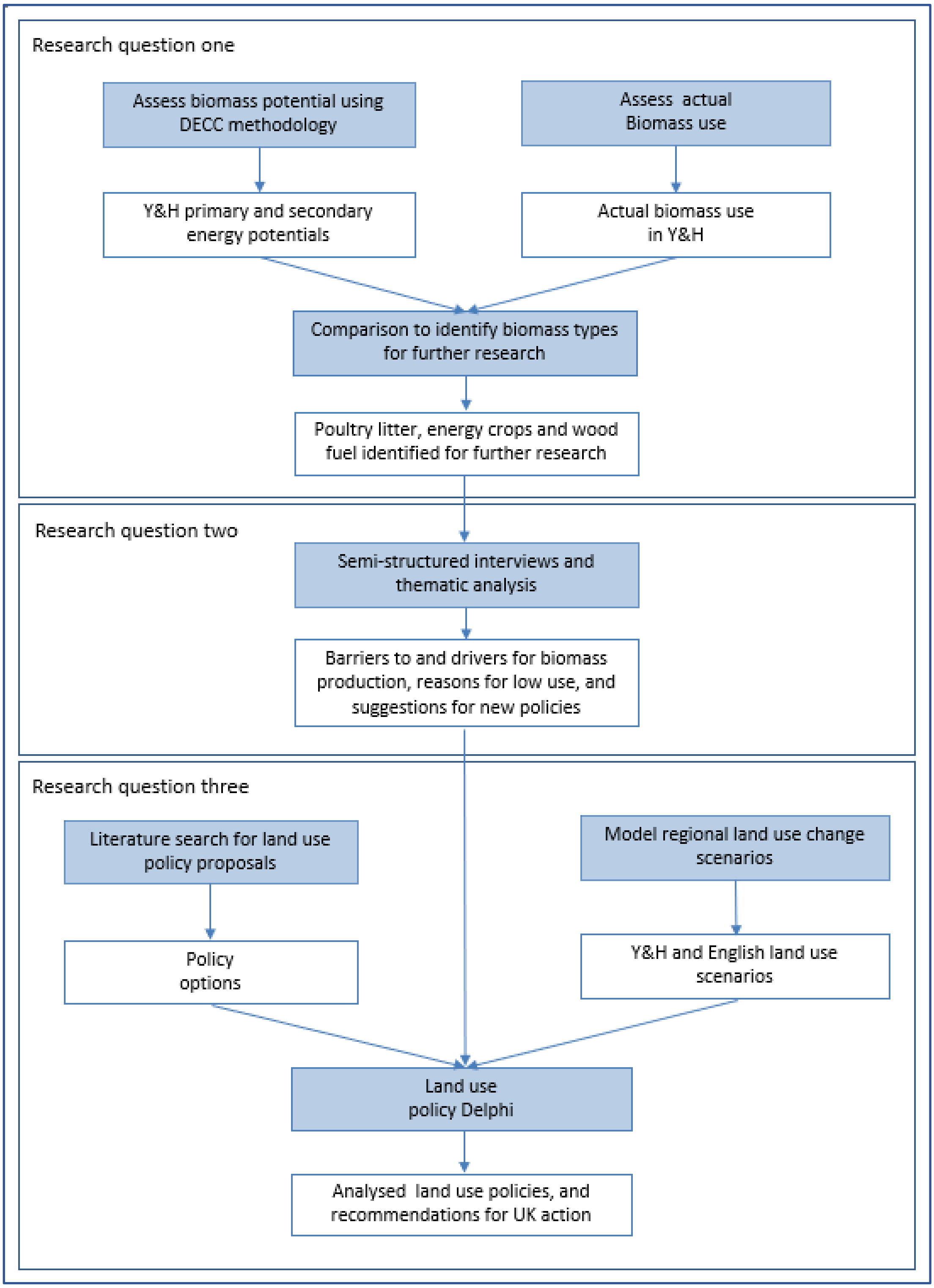

Figure 4.1 Overview of main methods used and data flow to answer the three research questions.
The methods are shown in blue boxes and the data in unshaded boxes.

The final phase of research aimed to understand which policies could increase the cultivation of PECs and woodland creation in the UK and thus increase the supply of biomass for bioenergy. The scope expanded from Y&H to the UK as most policies are set at the UK or national level. The third research question, '*What policies would be effective in increasing the production and use of biomass for bioenergy to help meet the UK's net-zero target?*' was answered by performing a policy Delphi. First the scale of woodland creation and PEC planting needed in England and Y&H was quantified, for three UK net zero land use scenarios, and four different approaches to allocating land use change. Then policies that could deliver significant increases in the area of land used for PECs and woodland were identified, from the stakeholder interview data, and from a literature search. The scale of potential land use change and the list of candidate policies were used as input to the Delphi which assessed the desirability, feasibility, and potential effectiveness of each policy. Finally, the policy Delphi data were analysed using a framework based on policy taxonomy, and the potentially most effective policies were recommended for adoption in the UK.

4.2 Identifying biomass types with potential for greater production or use

Section 3.1 reviewed the different approaches that can be taken to biomass assessments. It concluded that there are no standard approaches to biomass assessment and most studies develop their own methods, to meet their own specific requirements for the geographical area of study, level of detail required and biomass types to be included. However, the DECC methodology (SQW Energy, 2010) had been defined to assess UK regional renewable energy potentials, and after a review, it was decided to adapt and expand this existing method for use in this study, rather than developing a completely new method.

4.2.1 The DECC methodology

4.2.1.1 Purpose and use

The *DECC Renewable and Low-carbon Energy Capacity Methodology: Methodology for the English Regions* (SQW Energy, 2010) was created for DECC (The Department of Energy and Climate Change) and the Department for Communities and Local Government, to assess the potential for low carbon energy generation in UK regions by 2020. The assessments were to be used in the definition of regional low-carbon policies, and regional energy projects. The methodology covers bioenergy and other renewable energy technologies including wind, solar, hydro, air and heat pumps, but excludes biofuels. The statistical assessments were intended to be relatively simple, for a non-expert audience, and based on readily available data, predefined assumptions, and proven processing technology (combustion and AD for heat and power). However, this simple approach has resulted in some shortcomings which are discussed in section 4.2.1.2 below.

Consultants carried out the assessments for each English region in 2011, and these were reviewed by the NNFCC, who found it to be a flexible and robust process despite identifying some minor issues, including uncertainty around the woodfuel supply and problems accessing some data. Consultants deviated from the standard approach when assessing biomass, in an attempt to improve the assessment, e.g. by using their own figures for the time for which heat was available from generating plants (NNFCC, 2012b). The Y&H regional assessment was carried out by AECOM (AECOM, 2011), who made some changes to assumptions. As well as reporting energy potential for the Y&H region it reported at local authority level, and at sub-regional level (LCR, Sheffield City Region, North Yorkshire, and East Yorkshire). It also contains an assessment of the actual *use* of biomass in 2011 in the region at local authority level, although this is not a part of the DECC methodology.

4.2.1.2 DECC approach

The methodology assesses most types of biomass that can be used for combustion or AD, using a supply or demand driven approach as appropriate. Data at local authority level is sourced from The Environment Agency, OFGEM, DEFRA, The FC, Natural England, and BEIS: some of it available through the Government data portal MAGIC (DEFRA, 2020c). One significant advantage of the methodology is that it identifies many datasets that provide relevant data, that could otherwise be hard to find, or which the researcher may not realise existed. The data from OFGEM, BEIS and DEFRA are still available, well presented and up to date, with data available for assessing biomass use as well as biomass potential. However, some data from WRAP, The FC, and the Food and Drink Federation has not been kept up to date and, if available, is often not as easy to use. This restricts the assessments of industrial and some commercial food waste, construction wood waste, and particularly woodfuel, making the methodology difficult or impossible to use in parts.

Although the aim of the methodology is to assess the biomass available in the future, little projection is involved, except for energy crops where ambitious potentials are calculated which involve significant land use changes.

The DECC methodology produces what is described as a *'realistic biomass potential',* which considers restrictions to accessibility and competition for biomass use, but not economic or environmental restrictions, see **Figure 4.2**. The assessment is closer to the usual description of a *technical potential* with some additional limited assessment of competing uses. It makes assumptions about the preferred use of each type of biomass and calculates the *potential installed capacity* rather than biomass energy potentials. A single-step conversion from mass of feedstock to installed capacity in MW is made. This obscures a range of assumptions, feedstock attributes and technical performance figures including: biomass moisture percentages, assumed energy content, energy conversion efficiency and load factors. This use of installed capacity is probably the biggest shortcoming of the methodology. It risks overstating the potential of a declining resource such as landfill gas, and understating the contribution of bioenergy compared with other low-carbon technologies e.g. biomass combustion has a load factor of 77 %, solar power 11 %, and wind power 28 % (BEIS, 2018a, p185).

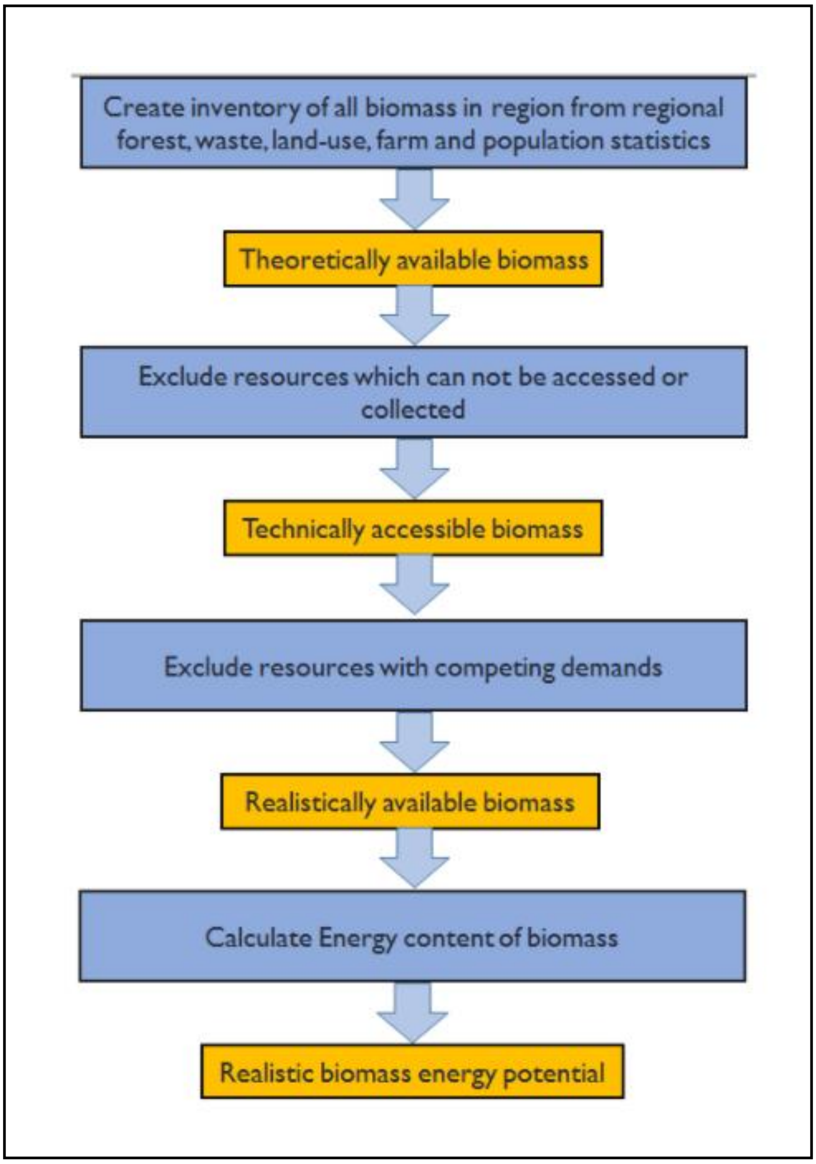

Figure 4.2 Main steps of the DECC assessment process to assess biomass potential

Since the methodology was devised in 2010, there have been many changes in bioenergy policy and incentives, technology, and agricultural practices; as a result the methodology is now out of date in several areas. Co-firing is no longer a relevant category for assessment (see section 2.2.2.2), and biomethane injection into the gas grid was not considered but is now an option for AD and landfill gas. Poultry litter could have included more types of bird, and could be assessed for use by AD as well as by combustion. Maize and other energy crops for AD were not included and bone meal and animal by-products were not assessed.

There are also minor limitations. The constraints are more rigorously modelled for some types of biomass than for others, e.g. straw constraints are considered in some detail while those for poultry litter are not. Care is needed to ensure that some resources are not double counted, e.g. sawmill waste and some commercial food waste could be assessed in more than one category.

No attempt was made in the methodology to assess the uncertainty in the results, but that was felt to be appropriate as it was intended to produce a simple, high level assessment using data which had no indication of uncertainty.

Overall, the DECC methodology provides the basis of a regional biomass assessment tool, providing a relatively simple methodology and comprehensive details of data sources, but some fundamental problems must be resolved to make it useable and these are discussed below. In the absence of up to date forest and woodfuel data there appears to be no simple method for calculating local woodfuel potential.

4.2.2 Research design for the assessment of biomass potential and use

The DECC method was selected for use in this study, but it had to be updated and developed to meet the research requirements. The main change was to add the calculation of primary and secondary energy potentials: which required the replacement of the single step conversion of mass of biomass to installed capacity with a full calculation involving calorific values, feedstock attributes, and technical performance figures. This avoided overstating the contribution of declining and intermittent resources.

Changes were also made to include new types of biomass, more up to date assumptions of competing demand for use, different processing technologies, and new data sources. These changes are summarised in **Table 4.1**. The individual calculations of biomass potential, the datasets used and the assumptions made can be found in Appendix E. Where possible more up to date data from the sources used by SQW Energy (2010) in the original DECC assessment were used, and where more data was required UK government sources, reputable agricultural advisors such as AHDB, or academic papers were used as data sources.

Table 4.1 Summary of DECC methodology and changes made

Biomass Type	DECC methodology	Changes made
Co-firing	Demand driven. Potential of 10 % of coal-fired power generation capacity.	Potential excluded from analysis now coal combustion is to end in 2021. UK produced biomass is assessed separately by type.
Miscanthus and SRC	Supply based. Three scenarios: • Low: area of land receiving planting grants under 2010 scheme, • Medium: all unplanted agricultural land. • High all non-protected arable and pasture land. Miscanthus or SRC allocated based on yield in each region. Assumes combustion for CHP.	Used only the medium scenario: planting PECs on unplanted agricultural land. One third of land allocated to SRC and two thirds to miscanthus in Y&H based on current planting patterns.
Woodfuel from managed forests	Supply based on Forestry Commission woodfuel tool (no longer up to date). Assumes heat only.	Potential based on current levels of extraction for energy
Straw	Supply driven based on cultivation of wheat and oil seed rape. Competition from animal bedding based on livestock numbers. Combustion for CHP	Barley straw included as volumes have increased. Supply constrained by demand for all agricultural purposes leaving 15 % for energy (AHDB, 2018c).
Waste wood	Driven by supply of sawmill, construction, and demolition waste. Combustion for CHP.	
Feedstocks for AD	Supply of cow and pig manure. Commercial food waste from WRAP data. AD and CHP.	Split into commercial food waste and manure.
Manure for AD	Supply driven based on cattle and pig numbers.	
Commercial Food waste	Supply driven based on WRAP data.	Excluded because of small scale of waste and increased focus on recycling and reducing waste (Wrap, 2014)
Maize	Not included	Demand driven based on current production for AD. Processed by AD and CHP.
Poultry litter	Based on supply of broiler litter. No constraint on use. Combustion for power.	Laying hens and turkeys added to supply. Combustion for heat.

Biomass Type	DECC methodology	Changes made
MSW	Supply driven for domestic waste only. AECOM restricted assessment to 35 % of MSW assumed to be biogenic and assumed only 25 % of biogenic waste is not recycled. Assumes combustion for CHP.	Supply driven based on MSW and some industrial waste. Assume 52 % of waste is biogenic (DEFRA, 2014).
Landfill gas	Based on actual installed capacity. Power only.	Based on actual generation.
Sewage sludge	Based on actual installed capacity. AD for power only.	Supply driven based on population and sludge production per person. AD and CHP.

The biomass potential assessment was carried out at local authority level, first in terms of installed capacity (as per the defined methodology to allow comparison with the 2011 assessment), then calculated as net primary and secondary potentials. Finally, sub-region and regional totals were calculated. The datasets used and assumptions made are listed in Appendix E and Appendix F, the energy conversion assumptions are listed in **Table 4.2** and the results are presented in section 5.1.

The biomass already being *used* in each local authority area of Y&H in 2018 was assessed using the latest data available at the time including: government statistics of energy generation, the OFGEM sustainability report (OFGEM, 2018a) (which contains details of all sustainable feedstocks qualifying for subsidies) the results of the BEIS woodfuel survey (BEIS, 2016) which reported on the use of domestic woodfuel in the UK, data on RHI payments (BEIS, 2018d), and the OFGEM *Renewables and CHP Register* for landfill schemes which earn RO certificates (OFGEM, 2018b). The actual use of biomass in each local authority area in 2011 (AECOM, 2011) was compared with the 2018 figures. Imported biomass was excluded from the assessment where possible and this prevented biomass use at Drax from distorting the findings. Where it was known that recently installed capacity was operational but was not showing up in the generation statistics, their contribution was estimated. For example the output of the newly installed EfW plants in Leeds, Allerton Park and Ferrybridge was estimated from the average EfW load factor (BEIS, 2018a, p184),applied to the installed capacity and assuming that only 52 % of the waste is from a biological source (DEFRA, 2014).

The biomass potential and biomass use figures were compared to understand how well local biomass is being used and to identify which types of biomass showed potential for increased use. The results can be found in section 5.1.

Table 4.2 Conversion efficiencies used in biomass assessments

	Value	Units	Reference
Electricity produced as % of energy input for CHP	35	%	(Banks, 2009)
Heat produced as % of energy input for CHP	50	%	(Banks, 2009)
Heat as a % of energy input for combustion	85	%	(SQW Energy, 2010)

4.3 Methods for understanding the actual production and use of biomass

Having identified that some types of biomass merited further research, the second research question, '*What are the barriers to, and drivers for, the greater production and use of biomass for energy production?*' was answered by carrying out a series of interviews to understand the decisions made by farmers and landowners that determine the current level of biomass production, and why the biomass potential is not fully exploited. As a theoretical framework can help to make sense of large amounts of data, three possible theories were assessed for their potential to form analytical frameworks for this research: diffusion of innovation, behavioural change theories and socio-technical transitions, which were all discussed in section 3.6.

4.3.1 Selecting a theoretical framework

Rogers' theory of the Diffusion of Innovation (DOI) was selected to model biomass production and use: with the social system comprising poultry farmers, arable farmers, and estate owners, who have networks of interpersonal communications and more formal structures through trade associations and publications. They may be influenced by opinion leaders within their group, and change agents such as consultants and salesmen. The diffusion model is recognised as a theory which is well suited to understanding and explaining the influences on individual actors or the small organisations who decide whether or not to adopt the well defined innovation of biomass production or bioenergy generation (see section 3.6.1). Having previously assessed the willingness of AD operators to adopt novel feedstocks (Brown et al., 2020), the researcher felt that DOI was particularly suited to analysing decision-making by farmers and landowners.

Behavioural change theories (see section 3.6.2) could have been used to analyse the influences on adoption decisions by considering biomass production and bioenergy use as technology adoption, but these theories were thought to be too limited in scope, particularly lacking in consideration of decision making over a period of time, and offer nothing that is not covered by DOI theory.

Socio-technical transitions theory (section 3.6.3) could also have been used to model biomass adoption. The existing crops or existing use of biomass could be viewed as the incumbent regimes within the landscape of financial pressures, regulation, and incentives. Innovations, such as new ways of using biomass or new crops, could be nurtured at a small scale in niches protected by incentives and investment support, until they reach the point where they are able to challenge the current practices financially and operationally. However, these theories are more often used for considering industry scale transitions such as national energy networks and are less effective at studying individual actions and decisions (Smith et al., 2005; Lawhon and Murphy, 2010). The technologies investigated were not going to fully replace large scale systems or existing regimes, instead they will, in many cases, sit alongside other technologies. They have passed the stage of needing to prove their technology although they may still need to be protected by subsidies or incentives. It was felt that socio-technical transformations were not the best models to provide insight into the barriers that are preventing the uptake of biomass growth and use, being more appropriate for studying whole system changes rather than decision making by individuals or families.

Rogers' DOI model indicated that the specific areas to be explored in the interviews should include: the perceived value of the innovation, the attitude of the interviewee to the innovation, the complexity, trialability and observability of the innovation, the routes by which knowledge of the innovation was communicated, the timing of the adoption and the background of the farmer. The adopters' experiences of the innovation were also to be explored and any discontinuance discussed.

4.3.2 Interview design

Semi-structured interviews are the most commonly used type of research interview, and their execution is widely described in literature (Kumar, 2005; Rowley, 2012; Wengrapf, 2001; Flick, 2015). Semi-structured interviews are particularly suited to interviewing experts (Kumar, 2005; Flick, 2015) where the expertise of the interviewee is of interest as well as their experiences.

Much literature assumes that interviews will take place face to face (Kumar, 2005; Wengrapf, 2001; Rowley, 2012; Flick, 2015) and those that do consider telephone interviewing view it as less desirable: likely to gather less rich data, with limited opportunities for building rapport, and no opportunity to respond to physical cues, but having the advantages of low cost, providing safety for both parties, enhancing access to geographically dispersed interviewees, and greater flexibility for scheduling (Drabble et al., 2015; Johnson et al., 2019). However, as Taylor (2002) argues, much discussion of phone interviewing is concerned with cold calling for opinion polling (e.g. Trochim (2008)); not the in-depth interviewing to be carried out in this research. Holt (2010) argues that richer data can be captured in a phone interview because there is no non-verbal communication which can be lost in transcription, and Stephens (2007) considers telephone interviewing to be a valid methodology for gathering data from elite, geographically dispersed respondents. It can be advantageous to carry out some interviews face to face and then continue with further interviews by telephone when the researcher has identified the key topics to be explored (Stephens, 2007; Shuy, 2002).

Socio-economic and demographic characteristics can also determine the most appropriate method of data collection (Kumar, 2005), and it was felt that the interviewees, who were all adults, being interviewed predominantly about their professional activities, and all likely to be comfortable using the telephone for business purposes, could be given the choice of either face to face or telephone interviews.

In-depth semi-structured interviews (Wengrapf, 2001; Flick, 2015) were selected to understand the production and use of biomass, and these were held with farmers, landowners, consultants, trade organisations and industry experts to understand the reasons for the level of use achieved by each of the selected biomass types. The interview process was designed and then submitted, together with all relevant documents, for approval by the University of Leeds ethics committee (see section 4.5).

These interviews captured qualitative data and were performed as a cross-sectional survey: collecting data at a single point in time but also gathered data on retrospective and prospective activities (Kumar, 2005). The research was a combination of exploratory, explanatory and descriptive (Kumar, 2005), depending on the specific objectives and level of current knowledge. Exploratory research of poultry litter use for energy was used because little research is available but explanatory research was used to understand the decision making for woodland and energy crop planting.

4.3.2.1 Interview script design

The questions in the interview script (included in Appendix A) were informed by the factors in the DOI framework (section 3.6.1) and topics from relevant literature (sections 3.3, 3.4 and 3.5). There was a mixture of specific questions and broad, open questions about the interviewee's experiences and attitudes.

Each interview started with confirmation that consent had been given for participation and use of the data, and consent for recording was requested. There were then some general question about the interviewee, their farm or job, and their experience, to put them at ease and set the tone for the rest of the interview, as suggested by Trochim (2008). Farmers and landowners were asked about their education, their sources of information, membership or organisations, participation in information networks, and experience of farm diversification projects, including renewable energy e.g. use of solar panels and biomass boilers.

Throughout the interviews, questions were tailored to the specific interviewee and their experience. Specific questions were asked on poultry litter, energy crops or woodland creation and management. Poultry farmers were asked about how much litter they produced, how they used or disposed of it, how they heated their sheds and whether they knew about on-farm combustion. Energy crop questions covered experience of annual and perennial crops, including costs, contracts, harvesting, and the impact of PECs on soils. Woodland interviews covered grants, financing, pests and diseases, skills, and education. Each discussion of an innovation covered features of the DOI model (Rogers, 2003, p170) e.g. previous practices, norms of their social system, the need for innovation, communication channels and factors influencing decision making. All interviewees were asked whether their experience was influenced by their location, and what the prospects were for the future use or production of biomass. They were also given the opportunity to raise any other relevant topics.

4.3.2.2 Selecting and recruiting interviewees

To get a full understanding of the cultivation of energy crops, creation of new woodlands, woodland management, and energy use of poultry litter, it was desirable to recruit the following types interviewee:

- Farmers who had planted miscanthus and removed it
- Farmers who had planted willow and removed it
- Current growers of miscanthus
- Current growers of willow
- Growers of maize
- Poultry farmers who combust litter
- Poultry farmers who land-spread litter
- Poultry farmers who sell litter
- Power station biomass contract manager
- Farmers who had created woodland
- Farmers who do and don’t manage their woodland
- Estate owners with experience of managing and creating woodland
- Charity, utility, and local authority landowners
- Commercial and public sector foresters.

The focus of energy crop and woodland research was on the attitudes of farmers and landowners to changing the use of their land and the scope of research did not extend to the operators of power stations using woody biomass. However, the poultry litter research was concerned with use of the litter, so the opinions of biomass buyers was of interest. The aim was to interview one or two interviewees of each type, and it was hoped that between 20 and 30 interviews would be carried out. Interviewees were selected for their knowledge and experience (judgemental or purposeful sampling) (Trochim and Donnelly, 2008) but there was some accidental or convenience sampling (Kumar, 2005, p244) of contacts made at conferences and socially. Snowball sampling (Trochim and Donnelly, 2008), where interviewees recommend others who have specific experience and may be willing to take part, was also used to find hard to reach groups, such as current growers of miscanthus, and commercial foresters.

Interviewees were selected from the researcher’s existing contacts, from contacts made at conferences, by contacting special interest groups and trade bodies, from contacts known to academics in the Bioenergy CDT, from online case studies, online searches, and through social contacts. Former energy crop growers were traced from the DEFRA Magic portal (DEFRA, 2020c) maps of land which had received PEC planting grants. This information was compared with current land use (from Google Maps (2018) or visiting the area) to identify farms where energy crops had been abandoned. The farmers were then contacted through directories or social networks.

Interviewees were recruited in person, by email or by telephone, using the approved recruitment scripts. Brief details of the research were given, and all interviewees were given copies of the information sheet and consent form (usually by email, but by post for one interviewee). If the interviewees agreed to be interviewed a convenient time was booked for a face to face or telephone interview. All communications with prospective interviewees were logged in a contact spreadsheet.

Details of interviewees are included in **Table 4.3**

Table 4.3 Interviewees' roles, experience, and locations.
Some details are excluded to maintain anonymity.

Interviewee	Experience	Location	Interviews Carried Out		
			Poultry litter	Energy crop	Wood-land
PF1	Poultry farmer. Broilers, land-spreads litter.	Yorkshire	✓		
PF2	Poultry farmer. Broilers, land-spreads litter.	Yorkshire	✓		
PF3	Poultry farmer in peri-urban location, raises pullets[2] and keeps laying hens. Exchanges litter for straw.	Yorkshire	✓		
PF4	User of poultry litter for on-farm combustion for heating and CHP. Planted woodland on farm.	Eastern England	✓		✓
MF1	Mixed farmer. Broilers and former maize grower. Considered litter combustion but land-spreads litter. Planted trees on farm.	Yorkshire	✓	✓	✓
PF&S	Poultry farmer and supplier of poultry litter boilers in UK.		✓		
PSM	Power station fuel manager.	UK	✓		
ADC1	AD consultant for poultry litter.	Y&H	✓		
ADC2	AD consultant for poultry litter and maize.	Y&H	✓	✓	
AF1	Arable farmer who grew willow and miscanthus in the past and has planted trees on farm in last 15 years.	Yorkshire		✓	✓
AF2	Arable farmer. Grew miscanthus and willow in the past. Now grows maize and has planted trees.	Yorkshire		✓	✓
AF3	Arable Farmer who grew miscanthus in the past and has planted trees in last 5 years.	Yorkshire		✓	✓
AF4	Current grower of miscanthus.	Yorkshire		✓	
AF5	Arable farmer. Grower of willow for more than 10 years and trial of SRF. Planter of woodland.	Yorkshire		✓	✓
LM1	Land manager and farmer. Miscanthus grower, former miscanthus contract manager.	Yorkshire		✓	

[2] A pullet is a young hen which will, on maturity, become a laying hen.

Interviewee	Experience	Location	Interviews Carried Out		
			Poultry litter	Energy crop	Wood-land
AF&A	Arable farmer and advisor on growing of maize for AD.	UK		✓	
MISCS	Employee of company offering miscanthus contracts and rhizomes.	UK		✓	
EO1	Landowner growing feedstocks for AD and large-scale forestry.	Yorkshire		✓	✓
EO2	Estate owner, farmer growing wheat for biofuels and managing large forest over 100 years old.	North-umberland		✓	✓
AF6	Arable farmer who has planted and managed woodland for over 10 years.	England			✓
SLO	Small upland landowner planning a small planting of trees.	Yorkshire			✓
HF1	Hill farmer, planted trees over 12 years ago and plans more trees.	Yorkshire			✓
EO3	Owner of woodlands over 100 years old and plantation woodland.	Yorkshire			✓
HCLO	Historic charity landowner.	England			✓
ULO	Utility landowner, managing catchment land and has major planting target.	Yorkshire			✓
LAF1	Local authority forester and manager of parkland.	Yorkshire			✓
LAF2	Local authority forester involved in Northern Forest project.	Yorkshire			✓
WCA	Woodland charity advisor to farmers.	UK			✓
WCR	Woodland charity researcher.	UK			✓
FTREP	Technical director of a forestry trade body.	UK			✓
FCF1	FC advisor on planting and funding. Former land agent. Woodland owner.	Yorkshire			✓
FCF2	FC advisor on planting and funding. Former urban forester.	Yorkshire			✓
MEG	Member of environmental group promoting planting of trees in Yorkshire.	Yorkshire			✓
WSUP	Woodchip processor and supplier. Forester.	Pennines			✓
FOR1	Manager with major UK forestry company.	Central and N. England			✓

Interviewee	Experience	Location	Interviews Carried Out		
			Poultry litter	Energy crop	Wood-land
FOR2	Manager with major UK forestry company.	Yorkshire			✓

4.3.2.3 Interviewing

Most of the interviews were carried out by telephone but five were carried out at the interviewee's place of work, and one was carried out at the interviewer's home. Most telephone interviewees gave verbal consent to take part in the research at the start of the interview, others completed the electronic form, and face to face interviewees signed a paper form at the start of the interview.

The approved interview script was followed, but this provided the opportunity to explore interesting topics in depth, and the questions were asked in the order that most suited each interview, to maintain a natural flow of conversation. Audio recordings were made of all the interviews and the researcher transcribed all the interviews verbatim ready for analysis. Express Scribe Pro software and a foot pedal were used to control replaying of the audio recordings, as it had been decided not to use automated voice recognition for transcription.

The first woodland interviewee was asked to test the process and provide feedback. One change was identified, the need to add pest damage to the interview questions, but the feedback was positive and his answers were included in the research data.

The aim was to recruit at least two interviewees from Y&H of each target type (listed above in section 4.3.2.2) and a decision had to be made on when enough interviews had been held. When two or more interviews of most types had been completed, 36 in total, additional themes were not needed during NVivo coding and it became clear that the research was approaching saturation, so no more interviewees were recruited.

After completing the interviews, the researcher attended a farm walk arranged by Terravesta and hosted by a current grower of miscanthus. This provided a useful opportunity to ask several growers and prospective growers about their attitudes and concerns. As no new themes emerged, it confirmed that saturation had been reached on the miscanthus research.

4.3.3 Analysing interview data

Deductive analysis (Saunders et al., 2012) of the themes from the interview data was carried out: formulating and testing theories and drawing conclusions on the reasons for adoption or non-adoption of biomass production or use. NVivo was used as an analysis tool with an initial set of codes for potential themes based on the interview questions, DOI, and literature review. Although DOI informed the analysis, resulting in a theoretical or deductive analysis, it did not restrict it, and it was not assumed that all themes identified would fit the DOI theory.

The thematic analysis of the interview data followed the six stages described by Braun and Clarke (2006): tailored for use with a theoretical framework and semi-structured interview data.

1. First the researcher increased familiarity with the research data during transcription of the interviews, noting initial ideas, identifying some powerful quotes, and carrying out additional literature searches for new topics raised by interviewees.
2. Initial coding of the interview data was carried out in NVivo, using the predefined codes, and generating new ones as required.
3. The researcher then searched for themes, sorting the codes into themes and collating data for each of the proposed themes, using tools such as the NVivo matrix framework. Different ways of presenting the data were explored including diagrams, tables, and matrices.
4. The themes proposed were reviewed and refined across all the interview data. At this stage the data were assessed for *'fit'* with DOI. The initial and final NVivo codes were compared to assess how much they changed during analysis.
5. New themes were named and defined. Each was analysed in detail for its contribution to the overall argument.
6. Finally, a results report was written to answer the research question, constructing arguments based on the research themes, including verbatim quotes from interviews.

Data for the three types of biomass was analysed separately and then an overall analysis was performed.

Although the interview scripts and the NVivo node structure had been built using the DOI theoretical framework, and this ensured that the relevant topics were discussed and analysed, the researcher felt that a more structured analysis could provide more insight. A further analysis was carried out, focussing on the core of the decision-making process followed by landowners. The key factors affecting decision making for annual crops, perennial crops, and woodland creation were compared to identify similarities and trends in the outcomes of decision making, and presented as a table.

The research validity was assessed, specifically determining whether saturation had been reached (the point where new interviews produce no new data), the interviewees had provided a good range of experiences, and bias was avoided. The results of the interview analysis can be found in Chapter 6.

4.4 Methods to identify and analyse perennial energy crop and woodland creation policies

The final research question *'what policies would be effective in*, *increasing the production and use of biomass for bioenergy to help meet the UK's net-zero target?'* was answered by identifying and assessing the policies which could deliver PEC planting and woodland creation, the two activities with most potential to increase the supply of biomass in the UK. It was clear from the results of the stakeholder interviews that significant government action would be required to overcome the barriers to both PEC planting and woodland creation. Specific reasons for the limited use of poultry litter had been identified from the interview results, so litter was not included in the policy research, and woodland management was also excluded because the interviews had already identified the success of the RHI in increasing woodland management (see chapter 6).

To put the challenge into perspective for the policy Delphi panellists, the scale of land-use change that could be required in England and in the Y&H region was modelled for three net zero scenarios. This modelling is described in section 4.4.1. Section 4.4.2 describes how the policy options were identified and section 4.4.3 describes how an analytical framework based on a taxonomy of public policy tools was defined to aid analysis. Section 4.4.4 contains background to the policy Delphi method and section 4.4.5 describes the design of the policy Delphi performed to gather expert assessments of the policy options and to project their outcomes.

4.4.1 Creating regional land use scenarios

Scenarios for reducing GHG emissions generally recommend desired levels of woodland, energy crop and agroforestry planting for the whole of the UK. The changes of land use will not be uniform throughout the UK and should depend on where the most suitable land is for each type of use, e.g. Scotland is likely to plant a higher than average proportion of trees while the top quality agricultural land of Lincolnshire may be reserved for arable farming. The impacts on the landscape will vary significantly throughout the UK. To understand the possible implications for England and the Y&H region, an Excel model was built to break down the UK figures and allocate land use changes to any UK nation or region, based on current land use and a defined strategy for allocation of woodland and PEC planting.

When identifying suitable land for planting PECs or woodland, the assessment is often based on either land grade or current land use (see discussion in section 3.7.1). Regional land-use data (DEFRA, 2019e) was used for consistency across the four UK nations, for consistency with CCC (2020a) and CEH and Rothamsted (2019) modelling, and to understand the level of *change* of land use.

The allocation of farmland to woodland and PECS in the model was based on the assumption that planting across the whole of the UK will be made on the type of land most suitable for the new land use, *irrespective* of its location, rather than by allocating planting targets by local GHG emissions, population or land area. The inputs to the model are:

- the current areas of farmland of each type in the country or region,
- the desired percentages of new UK planting of woodland and PEC to be made on each type of land (the *land allocation strategy*),
- the total area of woodland and PEC planting for the UK in the scenario (e.g. CCC *Speculative*)
- the percentage of remaining arable and pasture to be used for agroforestry.

The outputs are:

- the areas of new woodland and PEC planting on each of the four types of farmland in the country or region,
- the resulting areas of farmland of each type in the country or region,
- the area of agroforestry to be created on arable and pasture land.

The allocation of land is carried out using the equations in Appendix B. For example, if 80 % of UK tree planting is to be on rough grazing and Y&H has 2 % of the UK rough grazing then 1.6 % of UK tree planting will be on rough grazing in Y&H. Rewilding and peatland restoration were not included in the model and it was assumed that the increase in the area of land used for development would be insignificant.

4.4.1.1 Running the model

Three of the recent UK scenarios discussed in section 3.7.1 of the literature review, covering a range of levels of ambition for planting PECS and woodland, were selected for modelling. Two initial land allocation strategies were defined, both reserving most arable land for food production, both using higher grade land (MAFF, 1988) for PECs than for woodland but with one strategy using more lower quality land (unsuitable for arable use) than the other. The national and regional allocations calculated were used as input to the first round of the policy Delphi to provide a local scale and context for assessing the potential policies. Following feedback from the Delphi, two more allocation strategies were defined and used as input to the model. The results of all 12 calculations are presented in **Table 7.3**.

The areas of land calculated for energy crop planting were then compared with the area of land used in the regional biomass assessment carried out at the start of the research (see section 4.2.2), to understand the scale of the challenge and the change in level of ambition since 2011.

4.4.2 Identifying policies to overcome barriers

Many of the stakeholders interviewed about biomass suggested policies which could be implemented to increase woodland creation and PEC cultivation. These were extracted from the interview data to start a list of potential policies, then academic and grey literature was searched for suggestions from pressure groups, charities, government bodies, and academics to add to the list. Similar or duplicated suggestions were merged before a final list of policies was ready to be assessed in the policy Delphi. The list of polices and their sources can be found in **Tables 7.4** and **7.5** respectively.

4.4.3 An analytical framework for public policies

The many types of policy available to governments and the role of policy analysis in designing and implementing policies were discussed in section 0. An analytical framework was required to help with the analysis of a large number of candidate policies. Policy studies often use analytical frameworks based on a taxonomy of policy instrument type, or on the degree of coercion involved, as discussed in section 3.8.4, or on a specific taxonomy defined for a particular study. For example when analysing local government climate change policies Bulkeley and Kern (2006) consider four types of governance: self-governing (the policies governing internal activities of local authorities), governing by authority (the policies that they can impose locally), governing by provision (covering services they provide) and governing through enabling (which covers education, provision of guidance on voluntary policies, and facilitation). Studies using a framework based on a more standard taxonomy as described above in section 3.8.4 include Pereira (2018) using only two types of policy (carrot and stick) in analysing agricultural policy, while the three types of policy recommended by Vedung are also used (Salazar-Morales, 2018; Nykamp, 2020; Bellamy et al., 2019). The four types used by Christopher Hood and Howlett are commonly used (Toth, 2019), e.g. by Lawrence (2018) in her assessment of policies to promote extraction of wood from forests.

Drawing on six different policy taxonomies, a framework for this study was defined using four policy types which, for clarity, are referred to as: Information, Regulation, Economic (including taxes and incentives), and Organisation. Although Vedung opposes the inclusion of an Organisation or Facilitation category it was felt that this could be an important area of policy and as such was worth including in the framework. The correspondence of the terms to be used here, with those used by Hood, Howlett, Balch, Vedung, and Doern, are shown in

Table 4.4. As there is no direct equivalence with the Lowi model (Lowi, 1972), an approximation has been made.

Table 4.4 Policy taxonomy to be used in analytical framework and the equivalence to other commonly used models.
Drawing on Lowi (1972), Hood (1983), Howlett (2011), Vedung (1998), Albanito et al. (2019) and Balch (1980).

Model	**Policy Types**			
This study	**Information**	**Economic**	**Regulation**	**Organisation**
Hood	Nodality	Treasure	Authority	Organisation
Howlett	Information	Treasure	Authority	Organisation
Balch	Informing	Incentives	Requiring with penalties	Facilitating
Vedung	Information	Economic means	Regulation	
Lowi	Constituent	Distributive and redistributive	Regulative	Constituent
Doern	Exhortation	Financial	Regulation	Public Enterprise

4.4.4 The Delphi method

Delphi is a forecasting, analysis, and decision-making method which has been used to gather opinions on complex problems from groups of experts since the late 1940s, when it was first developed for use on USA defence projects (Landeta, 2006; Turoff, 1970). The underlying theory is that a group of experts will produce better predictions or decisions than individuals (hence the name alluding to consulting the Oracle of Delphi for predictions (Hasson et al., 2000)). It is still used in a wide range of research, prediction and scenario building applications where the views of a wide range of expert stakeholders are sought, including in climate change and water policy (de Loë, 1995), nursing (Meskell et al., 2014; Crisp et al., 1997), education (Manley, 2013), environmental policy (Wright, 2006), bioenergy (Rikkonen and Tapio, 2009), agri-food policy development (Frewer et al., 2011) and government scientific planning (Government Office for Science, 2017).

Opinion varies as to the key characteristics of the Delphi process, and to what degree these can be adapted, but they are generally considered to include: anonymity, the use of a panel of participants with in-depth knowledge who do not meet each other, at least two rounds of structured dialogue or consultation, the emergence of consensus, and the use of a knowledgeable facilitator or research team, (McKenna, 1994; Tapio et al., 2017; de Loë et al., 2016). McKenna (1994) also views the use of frequency distributions to identify patterns of opinion as a core feature.

Anonymity is central to the process. The panel members are all known to the researcher but their identity is generally kept from each other, as this removes power relationships and the risk of strong personalities dominating face to face discussions, prevents prejudices rising from the participants' background organisations, and removes the fear of losing face. However, there may be reasons for not maintaining anonymity, such as holding a group workshop, or because it may be important to identify the organisations involved (Tapio et al., 2017). When panel members view themselves as representatives of their organisations they may be more committed to the process but it is important to understand whether responses are personal or those of their employer (Tapio, 2003).

A traditional Delphi is made up of multiple rounds, where the output of each round feeds into the next, and the rounds continue until consensus is reached. Thus, the number of rounds may not be known at the start of a Delphi process. However, consensus may not be expected or desired (Tapio et al., 2017), and Linstone and Turoff (2011) argue strongly that traditional Dephi processes seek stability of opinion and not consensus. The first round often gathers issues or ideas, and the responses are synthesised and returned to the panel for evaluation. The input to the first round of a Delphi can include scenarios for evaluation to help generate ideas, plans or strategies (Rikkonen and Tapio, 2009). The second round often evaluates the issues using either a rating system or written evaluation, then the outcomes are displayed graphically, in tables or in written evaluations. Later rounds of discussion refine this evaluation or identify new areas of enquiry (de Loë et al., 2016; Hasson et al., 2000) and opportunity should be given to gather comments and opinions outside the simple answers to questionnaires (de Loë, 1995).

The tools used in the different rounds include interviews (either face to face or by telephone), questionnaires for which software is available (allowing asynchronous or synchronous activity), and group workshops or seminars, particularly in later rounds when participants have already had an opportunity to express their individual views (Tapio et al., 2017).

The advantages of the Delphi process include being able to facilitate interaction in groups of up to 50 people at a lower cost than traditional workshops (de Loë, 1995; McKenna, 1994). It allows remote consultation and pooling of knowledge without the problems that group dynamics can cause at workshops (Bailey et al., 2012), and can deliver more novel and high quality of ideas from groups of people who would not otherwise come together (de Loë, 1995). However, it has been criticised for delivering breadth rather than depth, preventing spontaneous interaction (de Loë, 1995), focussing too much on reaching consensus, suffering from bias in the choice of participants, and can suffer from respondent attrition as the rounds of consultation progress (Bailey et al., 2012). Attrition can be mitigated by making the level of commitments clear from the outset, providing reminders, using personalised correspondence and minimising the time between rounds (Meskell et al., 2014). Personal contact in the early stages of a Delphi can improve response rates later on (McKenna, 1994).

4.4.4.1 The policy Delphi

The way in which the Delphi technique has been used and its purpose have been significantly changed by researchers over the years (Crisp et al., 1997). The *classical* or *traditional Delphi*, the *policy Delphi*, and a third variant, the *decision Delphi*, all have different goals but very similar formats and methods, and in practice a Delphi may contain elements of all three (Rauch, 1979). The *policy Dephi* variant defined by Turoff, is for identifying and analysing a complex range of policy options while the *decision Delphi* aims to generate ideas and provide decision-makers with the strongest arguments for and against different resolutions to an issue (Turoff, 1970). While the participants in a *classical Delphi* are impartial experts those in a policy Delphi are in effect lobbyists. It is important to clarify the stand points of the lobbyists and it is important that all relevant groups of stakeholders should be represented. The policy Delphi allows the lobbyists to react to, and assess, different viewpoints, and the arguments for those positions and ultimately deliver these opinions to policy makers (Rauch, 1979). The suitability of the method for addressing complex policy questions, involving a multitude of issues, is well established (de Loë et al., 2016).

A policy Delphi usually has two or three rounds (de Loë, 1995). A common approach is to gather policy ideas or issues in round one, rate them in round two and present the ratings graphically or statistically, ready to review the ratings in round three (Hasson et al., 2000). The first round can gather large amounts of data if panellists are asked to raise all their issues or ideas. The temptation for researchers to reduce the volume of data by discarding infrequently occurring items should be avoided as this is inconsistent with the principles of the Delphi approach. The volume can be limited by either restricting the number of suggestions from panellists or in some studies the researcher supplies the initial data for appraisal, but care must be taken to avoid introducing bias (Hasson et al., 2000).

It is important in a policy Delphi that the researcher, taking the role of facilitator, is familiar with the subject matter. Turoff (1970, p.84) warns that the panel members '*will not be willing to spend time educating*' the facilitators and he recommends that all the obvious questions and issues should be included in the process before the panellists are asked to address the more subtle aspects of the problem. The researcher also needs administrative skills, to manage the data, and communications skills, to gain commitments of participants (Hasson et al., 2000).

4.4.4.2 Likert scales

In Delphi processes the two most common methods of assessment are ranking and rating. When a large number of judgements are being made, rating using a Likert scale is recommended (Turoff, 1970). A Likert scale can be used to record individuals' attitudes on a single scale that covers both negative and positive responses (Likert, 1932). Generally an odd number of points on a scale is recommended (usually five or seven), but for a policy Delphi, where the aim is to force a choice and identify issues, an even number of options, general four, is proposed by de Loë (1995), and used by Kattirtzi and Winskel (2020), and Meskell et al. (2014). This forces participants to make a choice: being undecided or neutral is not an option, although *no response* is a valid fifth option when they are genuinely unable to form an opinion.

There has been much discussion on the best way in which to treat Likert scale data: particularly on whether the data can be treated as ordinal or metric (Liddell and Kruschke, 2018; Kuzon et al., 1996). Although Likert scale ratings are often assumed to have equal intervals between values, and are analysed using metric models e.g. by calculating mean ratings and standard deviations, this can lead to systematic errors in interpretation, especially failing to identify divergent opinion (Liddell and Kruschke, 2018). Jameson (2004) considers Likert scales to be ordinal measurements i.e. they have a rank order but the intervals between values cannot be assumed to be equal. If the intervals were equal (interval data) then it would be valid to treat this data as metric and analyse it as such. However, the ordinal data in a Likert scale represent individual verbal responses and it is more appropriate to use the mode or median value, or to describe frequencies or percentages of response in each category. Bar charts are commonly used (de Loë et al., 2016) and divergent stacked bar charts are particularly recommended (Heiberger and Robbins, 2014) in preference to grouped or divided bar charts as they are easier to read, allow easy comparison of individual entries and take up less space (Robbins and Heiberger, 2011). Carifio and Perla (2008) argue that Likert scale ratings can be assumed to be interval data and analysed as such, but suggest using a high number of points such as eleven. However, Sullivan and Artino (2013) recommend that unless the data follows a classic normal distribution, displaying the frequency distribution of responses is likely to be more helpful.

4.4.5 Policy Delphi design

The aim of this phase of the research was to assess the policies that could be used to deliver significant increases in woodland creation and PEC cultivation in England: to understand how effective each policy could be, and to identify potential problems, unintended consequences, and interactions with other policies. Policies for delivering peatland restoration, determining land allocation for settlements, encouraging hedgerows and rewilding are *not* included in this research, which is focussed on woodland and PECs only, but these other land use changes could have an impact on the policies that are being assessed.

Initially a workshop was considered to discuss policies with a group of experts, but Covid-19 restrictions in spring 2020 made this impossible. The policy Delphi appeared to be an ideal method for gathering opinions from a group of experts without any need for travel or for face to face meetings.

Figure 4.3 shows an overview of the policy Delphi design. The list of possible policies to be reviewed (section 4.4.2) could have been created in the first round of a Delphi by asking the panel for suggestions. However, by compiling this herself, as discussed by Hasson (2000), and adopted by Frewer (2011), the researcher removed the need for their involvement in this step, thus reducing the number of rounds needed from the usual three for a policy Delphi to two: one to assess and update the initial policy list and identify issues, and a second round to react to the issues raised in round one. This minimised time discussing well-recognised policy proposals, focussed attention on the subtleties of policy making, and indicated that the researcher was already familiar with the proposed policies. Individual telephone consultations were selected as the method for the first round of consultation, and follow up review calls for the second round. For individual discussions with a small group, it was felt that there was no need to use Delphi software.

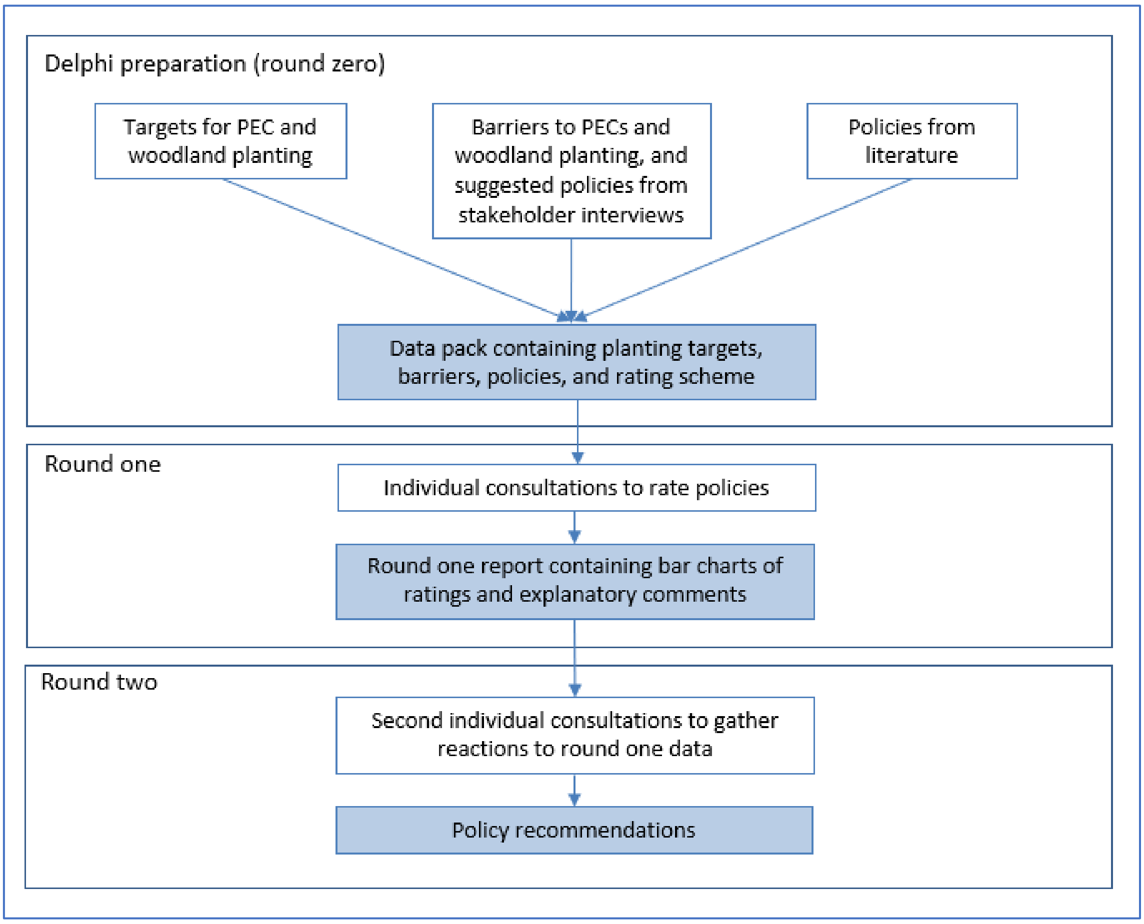

Figure 4.3 Overview of the policy Delphi design
The outputs from each round are shaded in blue.

The attributes to be assessed must be determined for each policy Delphi. Turoff strongly recommends rating the *desirability* and *feasibility* of policies and provides examples of scales that can be used (2002, pp. 86 - 87). He also suggests that *importance* and *confidence in the reliability of the argument* are two other attributes which could be measured. Hilbert (2009) synthesised all the factors into a single rating of the *impact* of a policy and Ludlow (2002), assesses just *effectiveness*. In this study the three attributes selected were: *desirability* in an ideal world, *feasibility* in the real world and potential *effectiveness* of the policy in the real world. The rating scales were defined, building on Turoff's definitions (2002, pp. 86 - 87), and these are shown in **Table 4.5**.

Table 4.5 Likert scale responses used in the policy Delphi
Adapted from Turoff (2002, pp. 86 - 87).

Attribute	Rating	Description
Desirability	Very desirable	Clearly beneficial.
	Desirable	Beneficial but may have minor negative effects.
	Undesirable	Will have some negative effects but may be justified overall in conjunction with other policies.
	Very undesirable	Extremely harmful or not justifiable.
Feasibility	Definitely feasible	Proven approach with no political or public objections likely.
	Possibly feasible	Possibly implementable, but not fully proven or some objections anticipated.
	Possibly infeasible	Some indications that it may be unworkable or unacceptable.
	Definitely infeasible	Unworkable or unacceptable politically or to public.
Effectiveness	Very effective	Very likely to deliver the desired effects.
	Effective	Likely to deliver some of the desired effects.
	Ineffective	Will have no effect either positive or negative.
	Counter productive	Likely to produce negative effects.

4.4.5.1 Recruitment

The policy Delphi required a panel of members who had either a policy role with an advocacy organisation (advocates), or a policy formulation role in government or research (analysts). While the interviews carried out in the previous stage of research were with people who understood the decisions made by landowners and farmers, the Delphi panellists all had to be familiar with the land use policies influencing woodland creation and/or PEC planting: including current policies, policy making processes and future expectations of land use policy making. This is a small group from which to recruit and a target of around ten participants in round one was felt to be both realistic and adequate to cover a full range of views, if recruitment was balanced between advocates and analysts and between woodland and PEC sectors. As Delphi exercises generally incur some reduction in participant numbers from each round to the next, it was hoped that from a first round of ten, six or more would participate in round two.

Recruitment was by email and each email followed an approved template, adapted to suit the individual recipient and the way their details had been obtained. Each email had attached an information sheet which gave details of the overall research, the consent form that had to be completed before participation started, and the data pack used in the round one consultation. One panellist was suggested by the researcher's supervisor and the others were identified from the internet, were delegates at conferences attended by the researcher, or were recruited with the help of other recruits (snowballing). The organisations approached included: government departments, special interest groups, the farming press, university research groups, research establishments, a miscanthus supplier and a large land management company.

Ethical approval was required for carrying out the policy Delphi, see section 4.5.

4.4.5.2 Round one

Consultations based on a data pack were selected as being the most appropriate technique for the first round of the study because of the small size of the group and the detailed level of discussion required. Individual discussions gave the opportunity to gather richer data than is possible from an online survey, which may be appropriate for a larger group. It was decided to rate the candidate policies rather than rank them because of the high number of policies to be assessed.

The consultations in round one could have been carried out either by phone or by video conference. At the time of the research, during the Covid-19 lockdown of 2020, videoconferencing technology such as Zoom and Microsoft Teams had rapidly become ubiquitous, and to some degree, notorious for technical issues in establishing communications, and delivering stilted, awkward discussions. Hanna (2012) expands Holt's (2013) argument, that telephone interviews can gather richer data than face to face interviews, to argue that Skype interviews can provide richer data than face to face interviews. Data collection via video conferencing during social distancing was supported by Lobe (2020), who made the assumption that it would be more like face to face interviewing than phone interviewing would. Archibald (2019) suggests that collaborative resolution of technical problems at the start of an interview can build rapport, or can be avoided by holding a pre-meeting to check technology. The researcher felt that video interviews would be no more effective in gathering panellists' views than audio only interviews, partly because of the positive experience of the telephone stakeholder interviews, but also because she expected that any technical issues would make the interviews seem unprofessional and waste the panel members' valuable time. A technical pre-meeting would have been completely unacceptable to participants and would have discouraged participation. Also, any problems with Wi-Fi service causing delays in sound can easily disturb the natural flow of conversation, and distract both participants. Telephone interviews were selected as the most appropriate tool. One first round consultation was booked on a videoconferencing platform at the request of the interviewee, but the audio quality was unsatisfactory and telephone was used instead. However, a video conference was successful with the same panel member in the second round.

Before running the policy Delphi process, ranges of regional and national planting targets were generated to put the scale of the challenge into perspective. These targets were derived from three UK level targets using two strategies for apportioning planting.

The data pack issued to panellists (included in Appendix C) contained: a brief explanation of the research carried out to date, an introduction to the policy Delphi process, lists of key barriers to PEC cultivation and woodland creation (identified in the previous phase of research), details of the land use change scenarios considered (**Table 7.1**), examples of how they would impact England and Y&H generated from the land use scenarios (**Table 7.3**), the Likert scales to be used in assessing the policies (**Table 4.5**) and the list of policies to be reviewed (**Table 7.4**) without details of their source and type. The full details of land use allocation calculations were included in an additional data section for members who were interested. The data pack had to be detailed enough to make it clear that the researcher was familiar with the key issues, but it was hoped that the document would take less than ten minutes to read, to avoid discouraging participation. Panellists were gently reminded before the call to have the document to hand.

At the beginning of each interview permission was sought to make an audio recording. Then if the consent form had not already been completed, consent to participate was requested. The rest of the interview script was followed with the responses to each question, and additional comments, noted by hand on a copy of the script. The recordings were replayed, if necessary, to allow comments to be recorded accurately; however, a full transcription was not made.

Although anonymity is an important feature of the Delphi process, panel members were asked if they would allow their role and employer to be disclosed, to provide context and authority to their contributions. The opinions sought from the experts were their own, and not those of their employers. However, it was expected that many of their views would be closely aligned with those of their employer, and others working in the same sector.

Participants were asked to rate seven different types of land use change for desirability so that the researcher could understand their personal, or their organisation's values, which could significantly influence their rating of policies. They were asked to explain any differences between their values and those of their employer. Panel members then reviewed the lists of barriers to woodland and PEC planting and had the opportunity to add any that they thought were missing. Then they rated the three selected land use scenarios for both desirability and feasibility. Finally, the full list of policies was rated for desirability (in an ideal world), feasibility (in the real world) and potential effectiveness (in the real world) for delivering the land use changes by 2050. The four-point Likert scales in **Table 4.5** were used, with *no answer* as a fifth option for when panel members felt genuinely unable to express an opinion through lack of relevant knowledge. The four-point scales were chosen to force an opinion. Participants were also asked to identify any problems, unintended effects, or interactions for each policy, and propose new policies to be added to the process. Opportunities were provided for contributing comments, explanations, and additional ideas at all stages.

Although there were many policies to be rated in each consultation, the process was designed to be completed within an hour to fit in with the diary commitments of the panellists. The consultation process and documents were tested, as recommended by Hasson et al. (2000), with the help of a volunteer with a good knowledge of land use change and woodland creation, but not experienced in policy making. The test results were not used.

All the data gathered in round one was recorded in a single Excel spreadsheet which was used to generate the divergent stacked bar charts, and also to extract the tables of comments. The findings were reported to panel members for review during the second round. Ratings were presented in bar charts, excluding no answer responses, and all the comments made to justify ratings were included in separate tables. To be consistent with the philosophy of the Delphi method, no interpretation or judgement was made by the researcher in producing the report, opinions were simply collated and presented for discussion. The bar charts for the different groups of policies are included in section 7.4 together with analysis of the responses

4.4.5.3 Round two

The second round comprised short, individual telephone discussions with panel members, to review the report of results from round one, and to give them the opportunity to comment on the contributions of others. It was not expected that any changes of opinion would be identified or any consensus reached. The data gathered in round one had identified many areas of divergent opinion and round two was predominantly an opportunity for panellists to provide reactions to the ratings and comments from round one, and to discuss issues in detail. Many consultations began with panellists commenting that they were not surprised with the findings, before proceeding to discuss particular areas of interest. However, some of the panellists reviewed all 43 policies and this took longer: up to 50 minutes. The data gathered in round two was recorded in a second Excel spreadsheet.

The panellists were able to view the list of roles and organisations of the other panellists in the round one report, and generally considered that a balanced panel had been achieved, and that useful findings had been produced.

4.4.5.4 Analysing the Delphi data

On completion of the second round of the policy Delphi the ratings from round one and the comments from both rounds were analysed. Initially, each of the groups of policies (general, woodland, agroforestry, and PEC) were analysed separately, further segmented by the four types of policy in the analytical framework (information, economic, regulation and organisation). The results can be found in Chapter 7.

4.4.5.5 Recruitment and attrition

Nine panellists were recruited for round one of the Delphi which ran from late June to mid-July 2020. Details of panellists are included in **Table 4.6**. The *role* column shows how the panellists considered themselves: as an advocate for a particular sector, as an impartial analyst or advisor, or a combination of both roles.

More panellists could have been reached by contacting, or following up contacts with lobbying groups. However, this would have risked distorting the results and, as many of their opinions had already been included in the list of proposed policies, there was limited benefit in doing so. The main gaps in the recruitment were BEIS and DEFRA who were invited but did not participate. It would also have been desirable to involve panellists from the National Farmers Union (NFU) and Farmers Weekly, but both organisations were too busy to take part. This recruitment took place during the first Covid-19 lockdown of 2020 when some organisations had furloughed or redeployed staff.

Eight of the first-round consultations were completed with a one-hour phone call. The ninth began as a phone call but the panellist asked for more time to consider the policy ratings, so submitted his responses in questionnaire format (in a document supplied by the researcher), an option discussed by Rowley (2012).

Table 4.6 Panel member details

Panel Member	Organisation	Job Description	Area of Expertise	Role
1.	Aberystwyth University	Research Group Leader	PECs	Advocate
2.	CCC	Senior Analyst	All	Analyst
3.	Forestry Commission	Principal Advisor for Climate Change	Woodland	Analyst and advocate
4.	Natural England	Climate Change Mitigation Specialist	All	Analyst and advocate
5.	Royal Forestry Society	Chief Executive	Woodland	Advocate
6.	Terravesta	Chairman	PECs	Advocate
7.	Strutt and Parker	Director of Research	All	Analyst
8.	UKCEH	Research Scientist	All	Analyst
9.	Woodland Trust	Director of Woodland Outreach	Woodland	Advocate

An invitation to participate in round two was issued to all nine panellists, together with a copy of the report from round one, and three accepted this invitation straight away. One reminder was sent to the remaining six, and five of them agreed to a second consultation. The round two consultations started in mid-August 2020, clashing with the peak holiday season so the period of consultations had to be extended to the end of September. As eight panellists did complete round two, exceeding the initial target of six, it was felt that the efforts to minimise attrition (by making the extent of involvement clear, personalising correspondence, and issuing reminders) had been successful.

4.5 Ethics, data management, and health and safety

Stakeholder interviews

Full ethical approval was required for the stakeholder interviews. The documents submitted for approval were: the ethics review form (which contained a full description of the research), the script for recruitment emails and phone calls to interviewees, the interview script, the data management plan, and the information sheet and consent form sent to each interviewee. Ethical approval was granted by the University Research Ethics Committee on 29 October

2018: approval reference number MEEC 18-008. Risk assessments were carried out for all face to face interviews, and these were recorded on the University's Rivo system.

Policy Delphi

Light touch ethical approval (a new process) was adequate for the policy Delphi. The proportionate ethics review form (containing details of the research including data management), the script for recruitment emails and phone calls, round one script, information sheet, consent form, and round one data pack were all submitted. Ethical approval (reference LTSCPE-003) was granted by the University Engineering and Physical Science Research Ethics Committee on 12 June 2020. No risk assessments were needed.

Chapter 5 Results of biomass assessment for Y&H

This chapter answers the first research question, '*Which types of biomass have potential for increased production or use in Yorkshire and Humberside?*' It contains the results of the biomass energy potential calculations made for Leeds, the LCR, and the Y&H region, and the assessment of the actual use of biomass in each of these areas, using the methods described in section 4.2.2. These results are analysed, the potential for all types of biomass to contribute to bioenergy generation are discussed, and three types of biomass with the potential for greater utilisation are selected for further investigation. This biomass assessment was carried out in 2018 using the most up to data available at the time, which were predominantly for 2016. The results of the *potential* calculations have not been updated as new data sets have become available, as it was not thought that the potential would change significantly. However, some developments in biomass *use* have been included as new plants have come into operation.

5.1 Results and discussion of results

The results of the biomass potential calculations in terms of primary energy in TJ y^{-1}, and the secondary energy potential for power, and/or heat in GWh y^{-1}, for each type of biomass are shown in **Table 5.1**, for the City of Leeds, LCR and Y&H. In the results tables, cells filled with an *x* were not calculated, either because they were not relevant or because data were not available. Where a dash appears in a cell for either AD or AD feedstocks, it indicates that the relevant figures appear in other cells: the energy potentials for manure and maize in AD appear in separate rows, and the total actual energy generated by all AD plants appears in a third row.

The individual calculations of biomass potential, the datasets used and the assumptions made can be found in Appendix E. The lower heating values were used to calculate net energy potentials in all cases (see section 4.2.2). All biomass known to be imported was excluded from the assessment e.g. the wood pellets used at Drax power station.

Table 5.1 Net primary and secondary energy potentials, and actual bioenergy generation

		Leeds					Leeds City Region					Yorkshire and Humberside				
Biomass Type	Assumed processing route	primary energy content of feedstock	electricity potential	actual electricity generated	heat potential	actual heat generated	primary energy content of feedstock	electricity potential	actual electricity generated	heat potential	actual heat generated	primary energy content of feedstock	electricity potential	actual electricity generated	heat potential	actual heat generated
		TJ	GWh	GWh	GWh	GWh	TJ	GWh	GWh	GWh	GWh	TJ	GWh	GWh	GWh	GWh
Miscanthus and SRC	Combustion CHP	148	14	0	20	0	2,747	267	32	382	0	7,940	772	65	1,103	0
Woodfuel	Combustion for heat	52	x	x	12	43	388	x	x	92	500	1,433	x	x	338	1,692
Straw	Combustion CHP	64	6	0	9	0	1,036	100	41	144	0	2,996	291	149	416	0
Waste wood	Combustion CHP	461	44	0	64	0	1,114	108	0	155	0	2,085	203	177	290	0
Manure	AD CHP	63	6	–	9	–	1,174	114	–	163	–	3,012	301	–	418	–
Maize	AD CHP	9	1	–	1	–	80	8	–	11	–	281	28	–	39	–
AD Actual only	AD CHP	–	–	8	–	42	–	–	45	–	94	–	–	168	–	410
Poultry litter	Combustion for heat	22	x	x	5	x	584	0	x	138	x	2,493	x	x	589	5
MSW (including food)	Combustion CHP	298	29	16	42	0	1,217	118	157	169	0	2,204	214	188	306	66
Landfill gas	Combustion CHP	628	61	61	87	x	1,811	176	176	251	x	4,191	407	407	581	x
Sewage sludge	AD CHP	192	19	0	27	x	781	76	14	109	x	1,391	135	33	193	x
Total		1,937	180	85	276	85	10,932	968	463	1,614	594	28,026	2,351	1,186	4,273	2,173

Table 5.2 compares the total consumption of power and heat for the region in 2018 (BEIS, 2020g) with the total secondary energy potentials from biomass (reduced by assumed electricity transmission and distribution losses of 7.6 % (BEIS, 2017a, p. 122)). No loss factor was applied to heat, and in practice there could be significant losses, but these would depend on the mix of heat use, e.g. in a heat network, for biomethane or a farm boiler. Biomass from Leeds could supply up to 5.1 % of the electricity *and* 3.7 % of the heat consumption in the city. For the whole of the Y&H region, local biomass could supply up to 9.5 % of the electricity and 5.9 % of the heat demand, or 6.8 % of the combined heat and power demand. These figures for Y&H are consistent with some of the national assessments discussed in section 3.2, but towards the lower end of the general range. This could be as a result of the conservative estimates of energy crop and woodfuel potential made here (see 5.1.1 and 5.1.2). Comparisons are also complicated by the inclusion of transport fuels in some assessments and their exclusion from others. The relative potentials of different biomasses in Y&H estimated here are generally consistent with the Ricardo Energy &Environment (2017) assessment for the UK. It can be concluded that the potential for biomass production in Y&H region is likely to be representative of the UK as a whole.

Table 5.2 Comparison of biomass secondary net energy potentials with electricity and heat consumption

Consumption figures for 2018 from BEIS (2020g) and electricity transmission and distribution losses of 7.6 % from BEIS (2017a, p. 122).

		Leeds	LCR	Y&H
Total electricity consumption in 2018	GWh	3,266	12,560	22,783
Potential electricity consumption from local biomass	GWh	166	894	2,172
Potential share of electricity consumption from local biomass	%	5.1	7.1	9.5
Total heat consumption in 2018	GWh	7,459	33,578	72,650
Potential heat generation from local biomass	GWh	276	1,614	4,273
Potential share of heat from local biomass	%	3.7	4.8	5.9
Total secondary net energy potential	GWh	456	2,582	6,624
Secondary net energy potential as percentage of heat and power demand	%	4.1	5.4	6.8

Figure 5.1 shows the primary energy potential of each biomass type in Leeds, LCR, and Y&H. It shows that energy crops have the highest primary energy potential followed by landfill gas, manure, straw, and poultry litter. It also shows that the City of Leeds has limited biomass potential, but as was also seen in **Table 5.2**, biomass becomes a more significant contributor to energy generation when the whole of the Y&H region is considered, and rural biomass (energy crops, woodfuel, straw and animal by-products) can make more of a contribution. Even for Leeds, which has 23 kha of farmland within its boundaries (more than other cities e.g. Sheffield 11 kha, Liverpool and Sefton 4 kha and Manchester 3 kha (DEFRA, 2019f)), the potential for biomass is limited.

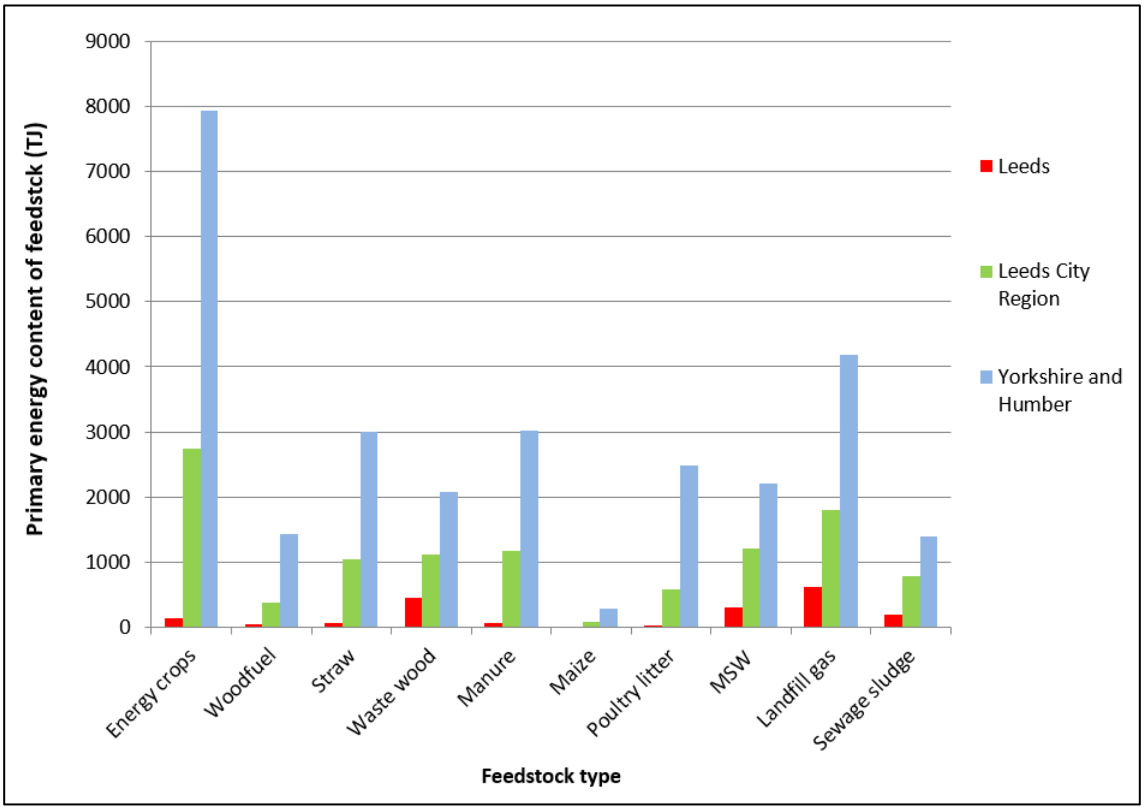

Figure 5.1 Net primary energy potentials by feedstock type

Figure 5.2 shows the secondary net energy potential for electricity generation, and the actual electricity generated in Y&H from each biomass type. **Figure 5.3** shows the secondary net energy potential for heat generation, and the actual heat generated in Y&H from each type of biomass. When considering secondary energy, the picture changes as a result of the efficiency of the assumed technology route. Biomasses used for heat generation, such as woodfuel and chicken litter, increase in potential relative to other feedstocks. It can also be noted that there is a lot of unexploited heat in the region. The biomass potentials and actual levels of use of each type of biomass are discussed individually in sections below.

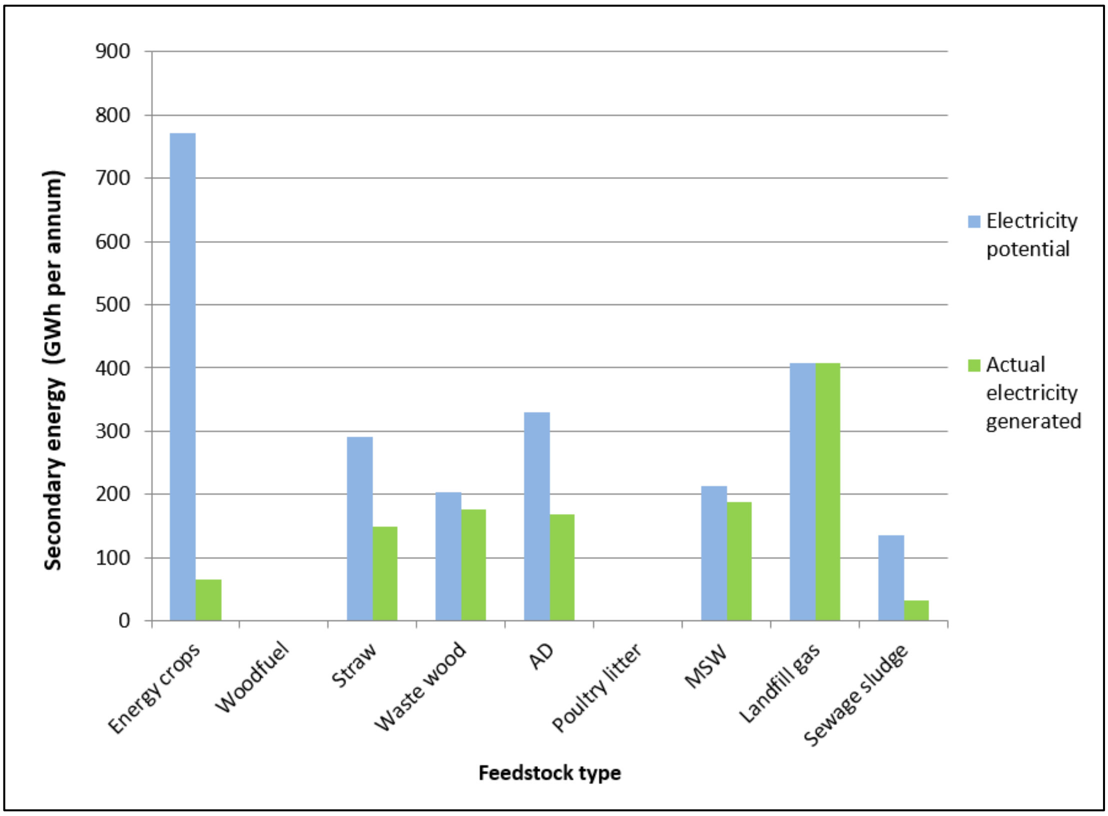

Figure 5.2 Net secondary potential for electricity generation and actual generation of electricity from biomass in Y&H in 2018

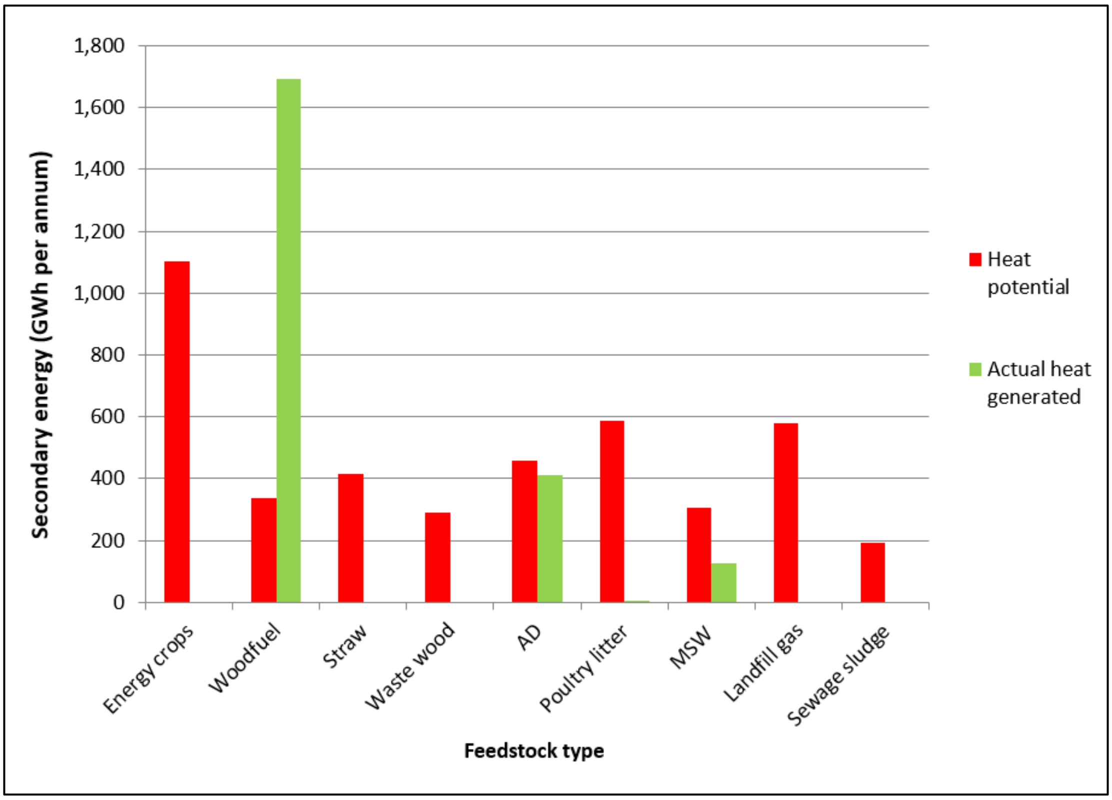

Figure 5.3 Net secondary potential for heat generation and actual biomass heat generation in Y&H in 2018

Figure 5.4 shows the main bioenergy generation sites in Y&H. The AD plants are widely distributed, but the largest biomass combustion plants are clustered in the south of the region: some on the sites of former coal-fired power stations which used coal from the Selby coal field. Many of the larger towns and cities the region have operational EfW plants, and in Hull a gasification plant has been under construction since 2016 (Walsh, 2021).

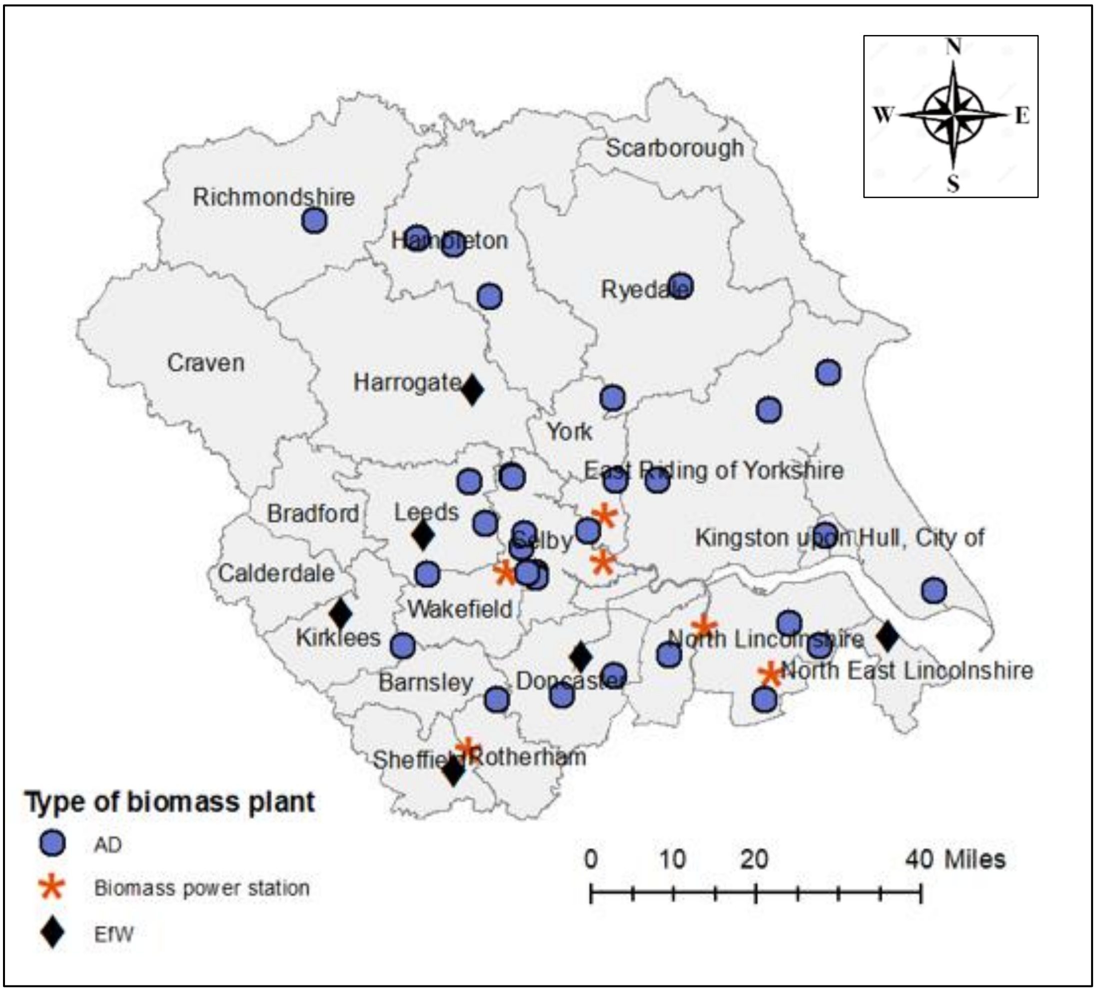

Figure 5.4 Location of main bioenergy plants in Y&H in 2018.
Data from ADBA (2018), NNFCC (2017a) and OFGEM (2018a). Base map ONS (2016b).

The biomass potentials and actual generation were also calculated in terms of MW capacity to allow comparison with the assessments made in 2011 (AECOM, 2011). These results together with the figures from the 2011 assessment can be found in Appendix D. The most striking change was the increase in electricity generation from imported biomass at Drax. However, when considering just domestically produced biomass there are notable increases in the contributions from MSW and AD, specifically the production of more *heat* from AD (from biomethane injection). There is also considerably higher use of wood for heat, but this may partly be because use was understated in 2011, before the results of the domestic woodfuel survey (BEIS, 2016) were available.

5.1.1 Energy crops

Miscanthus and SRC showed the highest energy potential despite a conservative scenario being used to estimate their potential (using unplanted agricultural land only). However, at the time of the assessment only 3 % of the potential was being used (excluding imported biomass). If all 30 kha of unplanted land in Y&H was planted with miscanthus then an additional capacity of 93 MW could be supported.

According to DEFRA's review of crops grown for bioenergy in 2018 (DEFRA, 2019b), miscanthus and SRC were not the main energy crops in the UK. Maize for AD and wheat for biofuels were the two main crops grown for energy and there was also some use of sugar beet. The total area of miscanthus grown in Y&H in 2016 was 1,779 ha down from 2,100 ha in 2010 (DEFRA, 2017a, Table H). The total area of SRC grown in Y&H in 2016 was 601 ha down from 911 ha in 2010 (DEFRA, 2017a, Table K). The most recent data available for 2019, in **Figure 1.2**. and **Figure 5.4,** shows that while the production of maize has increased over this period, the cultivation of SRC has decreased, and the area of miscanthus dipped before a slight recovery.

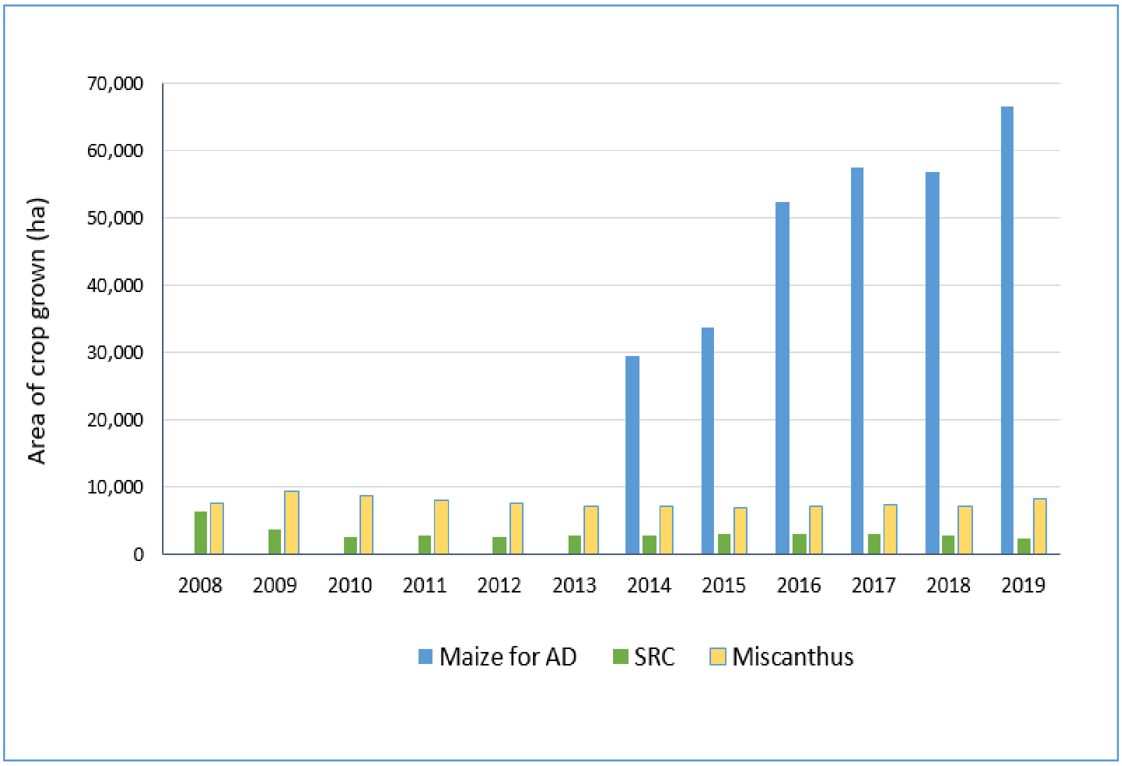

Figure 5.5 Areas of energy crops grown in the UK
Data from DEFRA (2020a).

Maize was separated from SRC and miscanthus in the primary and secondary energy assessments as it will be processed by AD. Maize potential was assumed to be the same as current levels of production, driven by demand from AD plants. Although demand could increase from this level, any increase will be determined by the size of the AD industry and constrained by restrictions on the proportion of dedicated energy crops imposed by RHI terms (BEIS, 2020d) and FIT payments (OFGEM, 2017b).

SRC, miscanthus and maize are all worth investigating further: to understand why the PECs have declined in popularity and why maize has proved to be a much more popular crop for growers.

5.1.2 Woodfuel from managed forests

As the original DECC approach (using the Forestry Commission woodfuel tool) could not be used (see methods section 4.2.2), the potential for woodfuel production was based on current levels of extractions and the current proportions used for energy. **Figure 5.1** shows that this resulted in a woodfuel potential lower than for most other types of biomass, but this figure is clearly a conservative one. In their 2011 assessment of biomass potential AECOM (2011) (see Appendix D) estimated that wood could supply 364 MW installed capacity of heat generation in Y&H: about four times the figure estimated from current wood production. As mentioned in section 5.1, availability of domestic woodfuel data (BEIS, 2016) has allowed more woodfuel heating to be identified than was possible in 2011.

Figure 5.3 shows that the actual use of woodfuel in the region (excluding imported wood combusted in power stations) is over five times higher than the local potential. This suggests that much of the woodfuel being used in small scale applications is either imported from other areas of the UK or from overseas, or is sourced locally from the '*grey market*' (informal gathering of wood) which is not documented (BEIS, 2016).

There are already initiatives in place to encourage the production of woodfuel in the UK (Forestry Commission, c2006) and it is recognised that more UK woodfuel could be sourced (Emmanuel-Yusuf et al., 2017). Although woodfuel would appear at first sight to be supply driven it is not simple to quantify. Not only does woodland have to be present, but there also needs to be a desire to manage it, or harvest it at particular date, unlike annual biomass crops. If the price is not right for the landowner, he or she can keep a wood crop indefinitely. Woodfuel can be a by-product of timber harvesting, or a product of woodland maintenance or the main product of harvesting wood that is unsuitable for timber.

Further research is needed to understand whether there is any scope to increase the local supply of woodfuel to meet the existing demand.

5.1.3 Straw

From **Table 5.1** and **Figure 5.2** it appears that only 51 % of the straw available for energy is being used in Y&H, but it is possible that as well as being used at a large scale at Drax and Brigg power stations (OFGEM, 2018a), some straw from Y&H was being combusted at Sleaford power station in Lincolnshire. No significant use of heat from straw combustion was identified in Y&H although it is used at Sleaford (Sleaford Standard, 2015).

Although there appears to be potential to use more straw in Y&H, plans for new straw power stations at Gameslack Farm and Goole (Tesco) have both been abandoned (BEIS, 2018c). Record high prices of £80 t^{-1} for wheat straw and £90 t^{-1} for barley straw (Prescott and Marston, 2018), were reached in 2018, suggesting that the supply was limited. Although prices were lower in 2019 they recovered in 2020 and by May 2021 both wheat and barley straw prices were over £100 t^{-1} (AHDB, 2021). It has been reported that power stations have struggled to source straw at acceptable prices and operators have been forced to diversify their fuel mix (Tolvik Consulting, 2020).

The researcher concluded from this evidence that there is unlikely to be sufficient straw available in Y&H for additional bioenergy use and it was not investigated further. It may be worth reconsidering the potential in the future if changes to the UK diet mean that cereal production increases and cattle numbers fall, increasing the straw supply and decreasing the demand for animal bedding.

5.1.4 Waste wood

Table 5.1 shows that 87 % of the waste wood available in Y&H is being used for power generation, and although confidence in the potential figures is low (as the latest data were from 2009, as discussed in section 4.2.2), it appears that waste wood is being well used in the region. There are presently waste wood power stations at Blackburn Meadows and Tansterne (OFGEM, 2018a). With increased focus on recycling, and competing demand for panel board, animal bedding and landscape materials (Tolvik Consulting, 2020; DEFRA, 2012), it is unlikely that the volumes of wood waste available from construction and demolition will increase. Waste wood was not selected for further investigation.

5.1.5 Feedstocks for AD

This category included the energy potential of commercial food waste and manures. Maize is discussed in the energy crop assessment (section 5.1.1), domestic food waste is included with MSW, and poultry litter is analysed separately.

The latest data available on commercial food waste for 2017 (WRAP and Food and Drink Federation, 2017) shows significant reductions in waste produced by Food and Drink

Federation members in the previous years. Using the conversion rate of 1 MW of energy capacity per 32,000 tonnes of industrial food waste used by AECOM, this would give a total UK energy potential of 3.5 MW, which was felt to be too small to be worth including in the energy assessment, so commercial food waste was not considered for further research. This data source is likely to understate the production of commercial food waste by limiting the survey to members; however, it shows a significant decrease in waste and together with continued pressure to reduce food waste it is hoped that the supply will diminish further in future.

The potential for manure from pigs and cattle was estimated as 3,012 TJ for Y&H, and it was estimated that 281 TJ of maize was being used in AD. However, it was not possible to identify how much biogas is being produced from manure, how much from food waste, and how much from dedicated energy crops other than maize, so a single figure for AD generation was produced. It was found that 168 GWh of power and 410 GWh of heat was being produced from farm fed and industrial AD in Y&H. The assessment of actual heat generation included both biomethane injected into the gas grid and heat generated at AD plants.

There may be scope in the future to use more manure but this will be limited to on-farm use for AD and will be constrained by the size of the UK AD sector, and by the competing demand for manure as an organic fertiliser. It was decided that there was insufficient scope for increased manure use to make further investigation worthwhile.

5.1.6 Poultry litter

Poultry litter in Y&H was found to have the primary energy potential of 2,493 TJ per annum, and if used for heat could supply 589 GWh per annum, but no use of heat or power was found in statistical data. However, the researcher was aware of some use in Y&H: one farm using litter for heating poultry sheds, one using it for AD, and one selling it to a power station outside the region. However, most litter is spread on land as a fertiliser, and only larger farms consider other options (Ford, 2018). This local litter use has been included in the results, but is not a full assessment.

The volume of litter arising could increase if changes to diets lead to a reduction in ruminant numbers and an increase in egg and poultry meat production. Changes to regulations controlling the storage and spreading of poultry litter, especially in NVZs (DEFRA, 2015a), and in peri-urban areas where land for waste spreading is limited, could dramatically increase the volume of litter available for bioenergy. If all the poultry litter in Y&H was available for power generation it could fully supply one new 44 MW power station (assuming current average load factors).

Poultry litter is worth further investigation. It is a more flexible feedstock than manure, being suitable for AD, and small or large-scale combustion, but currently little is used for energy in Y&H.

5.1.7 Municipal solid waste

When assessing the use of MSW, new plants in Leeds, Allerton Park (North Yorkshire), and Ferrybridge were included, although their generation statistics were not available in 2018. However, they were operational so their contribution was estimated. **Figures 5.2** and **5.3** show that 88 % of the power potential and 21 % of the heat potential is used in the region. Only Sheffield EfW plant was generating useable heat, but Veolia in Leeds will also be using heat for district heating in the future (Vital Energy, 2018).

This assessment may overstate the percentage of MSW used because the estimate of MSW available may be understated. It was assumed that 75 % of waste would be recycled (as suggested by AECOM (2010)), based on the recycling targets for England by 2020 (DEFRA, 2007), which is much higher than the levels of around 45 % being achieved in Y&H (DEFRA, 2017c). Thus, more MSW may be available currently than predicted, although it would be hoped that this will reduce in the future. It is also possible that Ferrybridge is using waste from outside Y&H, inflating the figures for MSW combustion. Nevertheless, facilities are clearly in place to use MSW.

MSW will not be investigated further because of the level of actual use, the pressure to recycle more waste, and the future increase in capacity under construction in Hull, all suggest that MSW has little scope for further exploitation in Y&H.

5.1.8 Landfill gas

As discussed in section 2.2.1.3, landfill gas is a declining resource, but it can be seen from **Figure 5.2** that it is still a significant contributor to bioenergy generation. No data were available on heat use from landfill and it was assumed to be zero. The assessment of potential was based on actual production and although installed capacity may increase slightly in future, gas production will decline with time, reducing the load factors of the installations, and this is a case where it would be easy to overstate the contribution of biomass by considering installed capacity in isolation. Landfill gas was not selected for further investigation because it should offer little scope for additional exploitation in the future.

5.1.9 Sewage sludge

Figure 5.2 shows that the level of use of sewage sludge for bioenergy was low, however, after the construction of the Knostrop waste water processing plant (Yorkshire Water, 2017), the use of sludge in AD will increase and there will be little scope for further exploitation in Leeds.

Yorkshire Water, who serve most of the Y&H region, planned to treat 100 % of sewage sludge in AD by 2020 (Yorkshire Water, 2019). AD is used to generate both heat and electricity on waste water treatment sites for use at peak times, with grid electricity used at off peak times. The heat can be used for pre-treating sludge (e.g. by thermal hydrolysis) to increase the methane production during AD (Bense, 2013).

Sewage sludge was not selected for further investigation because of projects already underway to fully exploit the resource.

5.2 Conclusions

This assessment of biomass potential has estimated that biomass from the Y&H region has the potential to make a significant contribution to supply energy in the Y&H region: up to 9.5 % of power and 5.9 % of heat. The level of actual use of locally produced biomass was low, suggesting there may be scope to increase the production and use of biomass feedstocks in the region. Imported biomass was excluded from the assessment of biomass use to prevent the wood pellets at Drax from distorting the assessment. However, there will also be movement of biomass between the regions of the UK which will have affected the results, especially for feedstocks which are known to be transported over long distances such as wood chips, straw, and poultry litter.

Biomass assessments are sensitive to the influence of subjective judgements, assumptions, and the accuracy of the data available. The energy crop potential estimated was particularly sensitive to assumptions on availability of land, but also to crop yields. The assessments of waste wood and MSW are sensitive to the assumptions made about recycling rates and competing demand. Similarly, the agricultural by-products are sensitive to the assumptions made about collection rates and competing demand. The competing demand for poultry litter is explored in section 6.1. All assessments are sensitive to assumptions about characteristics of feedstocks such as moisture contents and LHV, which in practice are highly variable. All assessments of secondary potential are sensitive to the assumptions made about conversion pathways and processing efficiency. Using the efficiencies in table 4.2 for all processes is possibly an oversimplification, e.g. the potential of sewage sludge is likely to be overstated because energy to process the sludge is not quantified.

The results here should be considered in context of the purpose of the assessment: to determine whether there is scope for increased production or use of any type of biomass, rather than an accurate assessment of the potential. There are some areas in this assessment where confidence in the figures is low, but the assessment has provided enough information to identify three types of biomass with potential for increased use in Y&H which merit further investigation. The assessment here, as was the case with the original DECC methodology, is focussed on the current potential rather than on the future possibilities which would introduce a new set of assumptions including improvements in yields and processing efficiencies.

It was concluded that sewage sludge, food waste, municipal solid waste, straw, waste wood, and landfill gas are all being well exploited in the region. Where there is still scope for additional biomass use projects are already under way e.g. the sewage sludge digester at Knostrop. Although there is potential for poultry waste and other manures to be better used, poultry litter was selected for further research because of its greater flexibility.

Energy crops have failed to develop as hoped: the use of maize has increased while SRC and miscanthus cultivation has failed to develop. Energy crops were also chosen for further research to understand why this is the case.

The final biomass type chosen for further research was woodfuel. The assessment failed to give conclusive figures on the availability of woodfuel. It is clearly an important type of biomass: relatively energy dense and easier to transport than most types, with local and imported supplies used in the Y&H region already, and with efforts already under way to produce more domestic woodfuel (Forestry Commission, c2006). Creating new woodland, and increasing management of exiting woodlands, could both increase the supply of woodfuel, and these both need to be investigated further to understand what prevents planting and management.

Little potential for greater use was found for the municipal resources (MSW, sewage sludge and landfill gas). The types of biomass with potential for greater production or use are all agricultural or forestry resources. There is little land available in urban areas for planting trees or energy crops, and although some land in cities has been identified for energy use (Grafius et al., 2019), that land is almost entirely socially and environmentally valuable park and recreational land, or rural farmland lying within a city's administrative boundary. The greatest potential for increasing the supply of biomass is in rural areas, where more land can be devoted to dedicated energy crops and woodland, so it was concluded that research should focus on rural production of biomass. Although Rossillo-Calle (2007) views residues as a widely under exploited resource at the heart of bioenergy, while plantations of energy crops are unlikely to be feasible, this appears not to be the case in Y&H. Here there appears to be little scope for increased use of residues but energy crops could have the potential for significant use, and further investigation would be worthwhile.

The desirability of minimising transportation distances of biomass is well recognised: to minimise costs, energy use, and GHG emissions. Maximum economic radii for road transport of 28–33 km for straw, 30–60 km for SRC, and 20 km for miscanthus have been suggested, while much larger distances for rail and sea transport can be economic (Commission On Environmental Pollution, 2004). Bauen (2004) views the economic limit for road transportation of biomass in some cases to be 150 km. Clearly the use of biomass within the region in which it arises is desirable. Because of the desire for relatively local use of biomass and the rural nature of the resource the researcher changed the scope of the research from biomass for the City of Leeds to biomass for the whole of the Y&H region. The next phase of research into the barriers and drivers for greater use of energy crops, woodfuel and poultry litter considers the whole Y&H region.

5.3 Reliability of the biomass potential assessment

The regional biomass potential method, developed from the DECC methodology, produced results which clearly identified which types of biomass had the potential for increased production or use in the UK. By following the method, the researcher became aware of some of the issues affecting the supply and demand for each type of biomass and the factors that could affect future availability, highlighting areas for investigation in the later phases of research.

However, the method developed did have some weaknesses. All assessments are reliant on the quality of the data and the validity of the assumptions made, and there will inevitably be inaccuracies in the results of this study. Although the calculation of most theoretical potentials are likely to be reasonably accurate (subject to uncertainty in yields and calorific values), assumptions of competing uses and accessibility will introduce inaccuracy into the net primary biomass potentials calculated. The secondary potentials will also be affected by the selection of conversion pathways and the assumed generation efficiencies. However, the primary purpose of this assessment was to identify types of biomass with potential for increased production, with the calculated potentials being less important, so the method did fulfil its purpose.

A particular weakness of the method was the assessment of woodfuel potential. Because of the lack of available, up to date data, the potential was assumed to be the same as the current production levels. This was the same approach taken by Tolvik (2020), and is almost certain to understate the woodfuel potential. Further work would be needed if a more rigorous assessment were required, with updated regional forecast data reflecting the current and future planting areas, species types, and predicted levels of active management. Phillips (2018), in his assessment of the UK woodfuel supply used the FC 25 year softwood (Brewer, 2016a) and 50 year hardwood (Brewer, 2016b) forecasts of available timber, and focussed his research on determining combustion performance and energy content of wood species grown in the UK. These FC timber forecasts were not used in this research because they did not provide regional data, and were known to be out of date (Ward, 2018). However, as it is more usual to transport woodfuel long distances than it is for other types of biomass, it may be appropriate to consider woodfuel resource for each of the four UK nations. Despite the lack of a rigorous assessment, it can be assumed that significant planting of trees, and increasing woodland management, will lead to a future increase in the production of woodfuel, so woodfuel was selected for further research.

The commercial food-waste potential was not included in the assessment because of the small future potential contribution; however, it was clear that that local authorities and private industries are aware of the potential for using industrial and domestic food waste in AD. With a focus on reducing food waste, it should be hoped that this is a diminishing resource, making only an insignificant contribution to the biomass supply in future. It can also be argued that food waste should be used as a feedstock for higher value processes than energy production (Royal Society of Chemistry, 2013; Biorenewables Development Centre, 2018).

The assessment of the potential contribution from energy crops was based on planting on unused land only, which was clearly an extremely conservative estimate of the potential. Also, no attempt was made to account for future changes to farming practices or plant breeding which could increase the productivity of energy crops. Estimating the potential of energy crops is an extremely complex matter, influenced by competition for land use determined by national policies, as well as the personal and economic factors influencing the decisions of individual landowners.

The methodology could be used for most agricultural and municipal biomass in any region of the UK, and it is likely that it could be used for EU countries: based on the assumption that the NUTS reporting followed by the UK before Brexit was standard across the EU, although data on competition for use could be hard to source. However, it would be more difficult to apply the method outside the EU because of different approaches to statistical reporting, and different practices in agriculture and waste processing.

The regional biomass assessment method could also be useful in making a quick assessment of the impact that changes to environmental regulations could have on feedstock availability e.g. changes to regulations on storing or spreading manure.

There are limitations in carrying out statistical, regional assessments of agricultural or forestry biomass. Regional boundaries can artificially split up the source of a resource, and the true distribution can be obscured. However, in this method, the assessment is made at local authority level before being aggregated at regional level, so it could be used to assess specific cross-regional areas e.g. a North Pennines area including neighbouring local authorities from the North East, the North West and Y&H regions, or an area near the Humber including some local authorities from the East Midlands as well as Y&H. When planning the use of rural biomass, a thorough spatial assessment may be necessary, particularly for woodfuel assessment where local authority data are limited.

Chapter 6 Results from stakeholder interviews

This chapter contains the results from the 36 stakeholder interviews carried out to answer the second research question, '*What are the barriers to, and drivers for, the greater production and use of biomass for energy production?'*, and is split into four main sections. Each of the first three sections covers one type of interview: poultry litter, energy crop and then woodland. The fourth section considers what can be learned from analysing all the interview findings together. Details of the interviewees' roles and experience can be found in **Table 4.3**.

For each type of interview, the themes identified from thematic analysis of the interview data are described, the main barriers or drivers are summarised, and the regional factors and interviewees future expectations are discussed (the full NVivo codebook showing the initial and final nodes is in Appendix G). Then a discussion is constructed using the DOI based analytical framework and referencing relevant literature. Although using thematic analysis and the DOI framework results in some repetition of findings, the DOI analysis was found to provide new insights into the decision-making process that were not apparent from thematic analysis alone.

6.1 Poultry litter interviews

This section contains the results of the nine poultry litter interviews. It includes a summary of the competing demands of litter presented in a matrix, and a discussion of the potential for greater use of litter for bioenergy.

6.1.1 Themes identified

The following themes were identified during analysis of interview data:

1. There is strong demand for litter as a fertiliser
2. Transport distances are key to litter use
3. On-farm combustion is only attractive to large farms
4. EU regulations are restricting uptake of on-farm combustion
5. Litter is a popular AD feedstock.

Each is discussed separately below, drawing on the personal experience of the interviewees and their wider knowledge of the poultry sector.

6.1.1.1 There is strong demand for litter as a fertiliser

The demand for organic fertiliser was strong and litter was viewed by farmers as a valuable commodity which was too good to burn. Farmers who had their own land generally spread their litter as fertiliser and sold any surplus to other local farms (*PF1, PF2 and MF1*). The amount that can be spread on any farm is dependent on many factors, including local environmental controls on spreading and storage of litter in Nitrate Vulnerable Zones (NVZ) to prevent nitrate damage from runoff (DEFRA, 2018c). It is also dependent on the farm size, soil conditions and type of farming practised. Farms with small flocks (between 50,000 and 125,000 birds) were usually able to rely on land-spreading on their own or neighbouring farms. Most small farms had well established customers for any surplus litter, so there was no need for many farmers to think beyond the usual practice of land-spreading.

Although litter disposal had been an issue in the past this was not now the case for small farms who have seen the price of litter increase recently:

> *'Actually, years ago it was a problem to get rid of, and it used to go down to the big power stations …. But with increasing cost of artificial fertiliser, and the recognition that poultry manure is good at building up humus[3] etc. in the land, prices of poultry manure have gone up quite dramatically. Whereas we were almost paying to get rid of it years ago, we are now charging £12 per tonne to anyone who has it, and I understand that some people are charging more than that.' PF4.*

Some farmers, including *PF3*, agree a *muck for straw* deal where they receive free straw from a neighbouring farm to use as bedding, in exchange for straw-based litter to be used as fertiliser. The true price of the litter can be hard to determine in these cases. Once a farmer has an established customer for litter, they may be unwilling to risk looking for a more lucrative contract that could be cancelled and result in a disposal problem (*ADC1*).

Only when insufficient demand for fertiliser results in a disposal problem, do producers look to energy as an option for some, or all, of their litter. This is more likely for very large producers (*PF&S*), especially those with few arable farms nearby, or farmers in peri-urban locations (*PF3*). The demand for litter depended on the number of local arable farms interested in using it as an organic fertiliser, which in turn determines the price that can be charged. Litter-fed power stations, which source most of their litter from large broiler producers, were not aware of any increase in litter prices although they had experienced increases in the price of straw (which they also combust) (*PSM*).

Many poultry farmers, such as *MF1* use contractors to clean out poultry sheds at the end of a cycle and remove the litter. The contractors now make no charge for cleaning, but keep the

[3] The organic component of soil.

litter which they sell to farmers or to power stations. This puts the decision about litter use into the hands of litter merchants.

6.1.1.2 Transport distances are key to litter use

Transport distance is always an important factor in determining litter use. Litter sold as fertiliser was always priced to reflect haulage costs, e.g. *'between £10 and £12 per tonne delivered' PF2* and *'£6 a tonne and they lead it away' MF1.* Supplying litter for AD was an option for farms near an AD plant, but the distances must be low to make this viable:

> *'There is one ... near York, but whether they would want to do the, what 20 miles, it's quite a distance because it's all about haulage.' PF1.*

Farms producing large quantities of broiler litter, and usually within a 50–70 mile radius (but sometimes further) of the power stations in Ely, Eye and Fife, can agree long term contracts to supply them. The power stations had contracts in place to source all the litter they needed, including contracts with farms in Lincolnshire, Humberside, and some parts of South and East Yorkshire (*PSM*).

Farmers who combusted their litter on-farm found the removal of the need to transport the fuel attractive, and they felt that this made it a sustainable fuel, e.g.

> *'For chicken manure you can take it as it is from the shed and move it to the bunker, so the carbon footprint collapses spectacularly by using the manure from the farm as a fuel' PF&S.*

6.1.1.3 On-farm combustion is only attractive for large farms

Two interviewees (*PF&S and PF4*) were using on-farm litter combustion to heat their broiler houses. The main drivers for adopting this technology were land-spreading regulations and a desire to reduce the significant cost of heating broiler sheds. *PF&S* was motivated to look for a new disposal route for his litter in the late 1990s when local land-spreading restrictions were suddenly imposed to tackle high phosphate concentrations, leaving him with a disposal problem. He was keen to exploit the energy content of his litter but did not think that power station sized combustion plants would be acceptable locally, so investigated small scale combustion. Future changes to regulations for litter spreading and storage, could create disposal problems and drive more farmers to look at energy uses, even on smaller farms:

> *'If they tighten up on land-spreading it will probably go down the power station route…it would have to go somewhere and it would just be a matter of who would take it really.' PF1.*

As well offering the advantages of reduced fuel costs and RHI payments for the heat generated, farmers found the environmental benefits of combusting litter attractive:

> *'the increasing cost of energy, and looking at the overall picture, [litter combustion] was ticking the sustainability box because, obviously, as long as we are growing chickens we require heat, and if we are growing chickens we are getting chicken manure, and if we can burn the chicken manure to make heat, then we have squared the circle if you like' PF4.*

Despite litter being an inexpensive fuel, most farmers chose to use wood chips or pellets for their biomass boilers. Although the price of litter has increased recently it is still much cheaper than wood, but farmers may later install a new litter boiler after initially installing a wood boiler:

> *'A colleague of mine did have a wood chip unit in and he has put a litter burning unit beside it because the cost of the wood pellets and wood chips are going through the roof.' PF4.*

Although on-farm litter combustion is eligible for RHI payments, the scheme is not stimulating the adoption of on-farm combustion. The farmers using wood chips or pellets to heat their broiler sheds all claimed RHI, were quite happy with woodfuel, and felt no need to look for further cost reductions or environmental improvements. Once a farm had invested in woodfuel combustion *PF1* thought that '*It would be almost pointless putting anything else in*', and *PF&S thought that 'the capital cost of that will keep them out of any more investment for maybe four or five years.'* While switching from wood combustion to litter combustion would further reduce fuel costs and retain eligibility for RHI payments, the farmers seemed to be content with using woodfuel subsidised by RHI.

The users of on-farm combustion were both happy with their experience and had demonstrated the innovation to groups of farmers from the UK and US. As well as solving their disposal problem and cutting fuel bills, the technology was popular with their neighbours because odours were reduced when farmers spread combustion ash instead of litter as a fertiliser. This could be an important factor in gaining planning permission for future poultry farms. Before the K and P rich ash can be used as a fertiliser, it must meet end of waste regulations (Environment Agency, 2012) and be approved by the EA. High ash volumes and slagging/fouling of the boiler have caused some problems but they have been overcome by the suppliers (*PF4*). The litter-fed boiler fitted in well with the production of litter on their farms:

the litter from one crop[4] of chickens being used to heat the next crop. There was less need for litter storage than for land-spreading (when litter has to be stored for months at some times of year until spreading is permitted). Being in control of your own litter disposal was found to be more convenient than having a contract with a power station:

> *'Invariably when I wanted to empty my farm they couldn't take it because they were broken down, or they were shut down for servicing, so we had to stockpile it then load it again. This was another thing that pushed me down this route. We are now in complete control.' PF4.*

The users of litter combustion made the step from direct gas combustion for heating their sheds (with associated humidity problems) to indirect heating from hot water pipes fed by the litter boilers. They were very pleased with the improvement in the environment for the birds and the resulting improvement in productivity. Hot water pipe heating can also be powered by gas, wood chip or wood pellet systems, and this improvement in conditions is not unique to litter boilers. The dry heating resulted in a drier litter which was then ideal for combustion. *PF4* has invested in a CHP plant to use spare litter to reduce the electricity costs on the farm. Although litter from broilers has a higher calorific value than litter from laying hens, the interviewees knew of at least two successful installations of on-farm combustion using laying-hen litter in the UK.

The high initial cost of litter combustion boilers means that many farmers view it as being suitable for only the largest of operations. There was widespread knowledge of on-farm combustion from articles in the farming press but smaller farmers felt that this was not a technology that was suited to their operation. Even a large new poultry operation (over 240,000 broiler flock) found the expense of a poultry litter boiler too high:

> *'That would have been another £500,000 so we thought it was beyond our means...we didn't think it was economically on… We still need to have a back-up of a gas heating system in the unit and it seemed a bit extravagant to have to pay for two heating sources to be perfectly honest. So we just stayed with the gas … We have spent enough.' MF1.*

Instead, this farmer used a contractor to clean the sheds and remove the litter which he thought went for combustion. While litter combustion technology is new, adoption is a large financial risk for any farm, but the adopters expected that if uptake improves then mass

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[4] A cycle of chicken production from chicks to fully grown broiler chickens is termed a crop.

production of the technology would reduce the cost, making it more attractive to smaller farmers. Even at current prices *PF4* expected the investment in litter burning to pay back within 7 or 8 years. Their boiler is heating two poultry units (with a total capacity of over 800,000 birds), so they stagger the crops to even out the energy demand which is highest when the chicks are young but decreases to nothing as the birds grow.

6.1.1.4 EU regulations are restricting uptake of on-farm combustion.

EU regulation 592/20014 for litter combustion (The European Commission, 2014) is restricting the uptake of on-farm combustion of litter (see **Box 1**). The two interviewees who were using on-farm combustion had significant regulatory issues to overcome initially, but were fully operational with compliant equipment. They both used boilers from the same supplier who had about 10 to 12 customers in the UK. Most other suppliers of boilers were, at the time of the research, not compliant with the regulations and were unable to supply litter-fed boilers. One supplier with a case study online appeared to have left the market, and another supplier has ceased to trade. During the recruitment of interviewees non-compliant suppliers and their customers were not willing to be interviewed. The problems with regulations were confirmed by the Animal and Plant Health Agency (APHA), the UK regulator of litter combustion for installations less than 5 MW (Reid, 2019).

Box 1: COMMISSION REGULATION (EU) No 592/2014 – The use of animal by-products and derived products as a fuel in combustion plant.

The regulations were developed to allow litter to be combusted on the farm where it was produced, under animal health regulations rather than the more onerous waste regulations, and apply only to plants of 5 MW capacity or less. The regulations stipulate that litter must be capable of combustion without any pre-treatments to qualify as a fuel which is a *by-product* of poultry production, and not a *waste* product. Litter cannot be co-fired with any other fuel such as wood chips or pellets.

The combustion temperature must reach 850 °C for a minimum of 2 seconds to ensure that harmful pathogens are eliminated. This is the same temperature required for the incineration of municipal waste (EU regulations 2000/76/EC) (The European Commission, 2000). Limits on the emissions of sulphur dioxide, nitrogen oxides and particulate matter are also specified.

PF&S explained that fluidised bed incinerators (Williams, 2005) could reach 850 °C, the temperature needed to meet regulations, but boilers adapted from wood-burning stoves could not reach this temperature. Co-firing litter with other fuels, such as wood chips, would mean that under EU law the process would be considered as the incineration of a waste material rather than the use of litter as a fuel, meaning that waste regulations would have to be applied. This failure of technology to meet the regulations is a significant barrier to increased combustion.

6.1.1.5 Litter is a popular AD feedstock

Litter is an attractive feedstock for on-farm AD plants. As well as having a high methane potential it helps operators meet the OFGEM stipulation of 50 % waste materials to qualify for maximum RHI and FIT payments (see section 2.6.4). Litter for *AD* is generally imported from another farm so is classed as a waste material (although for on-farm *combustion* it is categorised as a by-product). The demand from AD plants was thought by interviewees to be another reason for the rise in the price of litter:

> *'Poultry litter is one of the quite prime products that can go into an AD plant to tick that criteria box with OFGEM … the demand on the supply of poultry litter has increased and therefore the price is going up …It's all about cost per cubic metre of methane production and poultry litter gives a more beneficial cost per cubic metre of methane than energy crops do, and therefore there is a demand.' ADC2.*

The use of litter from another farm comes with additional waste regulations and permitting, which may not prevent its use but is an extra burden for operators. As broiler farmers produce batches of litter every few weeks throughout the year there are fewer storage requirements than for annually harvested energy crops.

The interviewees found that the amount of litter that can be used in AD was limited by its nitrogen content and the proportion that can be used is dependent on the technology. They found that problems could be avoided by limiting the proportion of litter, usually to 15–20 % by fresh matter, of the AD feedstock mix (*ADC2*).

6.1.2 Drivers and barriers for energy use of poultry litter

The drivers for, and barriers to, energy use are summarised below in **Table 6.1**.

Table 6.1 Drivers and barriers for energy use of poultry litter

Drivers
Land-spreading regulations limiting the amount of litter that can be spread
Lack of local arable farms to buy litter
Desire to reduce cost of heating on broiler farms
RHI is payable to AD plants digesting litter
On-farm combustion may make planning approval for poultry farms easier to obtain
Barriers
High demand for litter as an organic fertiliser means less is available for energy use
High initial costs of on-farm combustion make it unattractive to small farms
Farmers already claiming RHI for woodfuel boilers have less incentive to adopt litter combustion
EU regulations for on-farm combustion prevent pre-treatments and are not currently met by all boilers
Transport distances limit litter use

6.1.3 Regional factors

Litter use was dependent on local conditions. The concentration of poultry farms, NVZ regulations, the number of arable farms, the number and location of AD plants and power stations were all found to affect the amount of litter used for energy generation in a region. Y&H has high levels of poultry and arable farming, has similar numbers of AD plants to other areas of the country, and parts of the region are near enough to power stations to sell litter to them. The interviewees felt that the use of litter for bioenergy in the rest of the UK would be determined by the same factors as in Y&H.

6.1.4 Interviewees' future expectations

Farmers were uncertain whether land-spreading would be encouraged in the future as a desirable use of litter, or whether N and P regulations would be imposed to restrict its use. This is probably the biggest factor that will influence the amount of litter available for energy. The AD consultants thought that there was little scope for increased AD capacity under the Government's policies in force at the time which were not encouraging AD. However, this could change and another period of expansion in the sector could be triggered by policy changes. Farmers who were combusting litter on-farm thought that its popularity would increase as technology matured and capital costs fell.

6.1.5 Summary of litter uses

Table 6.2 shows a summary of the uses of litter available to poultry farmers, the factors which influence decision making and hence the amount of litter available for energy use.

Table 6.2 Summary of the uses of litter and their attributes

	Land-Spreading	Power station combustion	AD (off-farm)	On-farm combustion
Energy generated	None	Electricity and small amount of heat.	Biomethane, electricity or CHP.	Heat and CHP for surplus.
Transport distances	Local	Up to 50–70 km	Local	Zero
Nutrients recycled	Yes N, P and K with humus.	Yes, P and K in ash.	Yes, N, P and K in digestate.	Yes, P and K in ash.
Suitability	Smaller poultry farms in arable areas.	Larger poultry farms or farms with a disposal problem.	Farms near farm-fed AD plants permitted to take litter.	Large flocks with high heat demand or farms with a disposal problem.
Initial cost to poultry farmer	Low	Low	Low	High
Perception	The default use, a valuable organic fertiliser.	For bigger farms with disposal problems.	Less well known, risky to abandon a land-spreading contract.	Only for the big farms. Very expensive.
Biggest drivers	A valuable organic fertiliser.	Disposal problems, long term contracts.	Financially attractive, disposal problems.	Disposal problem, energy cost reduction.
Biggest barriers	Spreading restrictions, lack of local demand.	Large volume needed, distance from power station.	Need to be near AD plant.	Expensive, RHI claimants have less incentive to adopt.
Experience of adopters	Valuable as fertiliser or to exchange for straw.	Long term disposal solution, but collection can be inconvenient.	Another market for litter.	Cheaper than wood-fuel, reduces smell, and convenient.
Prospects	Could be limited by tightening of land-spreading regulations.	More power stations may be needed if use is to increase.	Little growth in AD currently predicted at time of interviews.	Could be more popular if technology costs fall and more boilers are compliant.

6.1.6 Discussion and conclusions

No literature had been found on the reasons why only a small proportion of poultry litter arising in the UK is used for energy generation. From the data gathered from stakeholder interviews, barriers to use and competing demands for litter were identified, which explain the current limited use of litter for energy generation.

6.1.6.1 Decision making

The DOI theory model for decision-making (Rogers, 2003, p170) is used here to structure the discussion of the interview results; particularly focusing on the decisions that farmers make when considering whether to adopt on-farm combustion of litter. The decision-making unit was generally a farmer, but for a family farm there may have been a number of partners from multiple generations involved.

Prior Conditions

For most farmers their previous practice, and the norm for their social system, was to dispose of litter by land-spreading on their own farms, or selling it to neighbours. Since the 1990s larger enterprises have been able to sell litter for combustion at power stations and now some farmers have the option of selling litter to local AD plants. The interviews found strong demand for litter for organic fertiliser and AD feedstocks, and recent growth in demand has resulted in an increase in price. Most of the farmers were aware of this increase, but the price was dependent on local demand. The power station buyer interviewed was not aware of an increase in price: suggesting that they were buying from farmers in areas with low demand for fertiliser. The price litter could achieve as a fertiliser is likely to be limited by the cost of competing artificial fertilisers. The value of the N, P and K content of poultry litter has been estimated at £21 per tonne (AHDB, 2018b), and this, together with haulage and spreading costs, will determine the maximum price that litter could achieve as a fertiliser.

The normal practice for heating poultry sheds and other farm buildings was to use biomass boilers or fossil fuel heating. Although air and ground source heat pumps, sometimes in conjunction with solar power generation, are also options for heating sheds (McDougal, 2017; Clarke, 2015) they were not used by interviewees, but the researcher has since found evidence of local use. Solar heating has also been proposed (Cui et al., 2020).

Only when disposal became a problem, or when farmers wanted to reduce their energy bills, were they motivated to seek new solutions.

The DOI can be used to analyse the propensity of individuals to adopt innovations and assign them to adopter categories (Rogers, 2003, p. 267). Attitudes to litter combustion and other farm practices (such as solar power, innovative crops, biomass boilers and farm diversifications) can be used to categorise the interviewees. *PF&S* was clearly an 'innovator' who developed new solutions to his problem, and *PF4* an 'early adopter' who sought new solutions. *MF1*, although not an early adopter, could be described as an 'early knower' (p. 174), who may be ready to adopt in the future, as either an early or late majority adopter. The other farmers could fall into one of the less innovative categories, although in most cases the innovation is unsuitable for their needs so no categorisation can be made. The innovation is still at a very early stage of adoption for the social system of UK poultry farmers.

Communication Channels

During all steps of the decision-making process, farmers were influenced through a range of communication channels. All were well informed: reading the farming press (Farmers Weekly, NFU magazine and specialist poultry publications such as Poultry News) and had networks of homologous friends, relatives and local farmers who provided information and advice. Some were involved in larger trade networks and most were members of the NFU, and they used professional advisors for specific projects. The farmers interviewed may have been better informed about options than poultry farmers in general as they were all sufficiently interested in energy generation to participate in the research.

Step I: Knowledge

The farmers seriously considering on-farm combustion were owners of large poultry units who were prepared to take the financial risk of new technology. They were interested in the environmental impacts as well as the financial benefits of using litter as a fuel. They sought new information to meet a newly identified need, either to cut fuel costs or to solve a disposal problem, using their existing communication channels, and also looked beyond their usual networks to access new sources of information.

Step II: Persuasion

During the persuasion step the farmers formed attitudes to the innovation. The perceived advantages of on-farm litter were: solving their disposal problem, providing the opportunity to reduce energy costs, reducing their reliance on others to transport litter, and reducing GHG emissions.

On-farm combustion was viewed as being compatible with farming cycles: litter from one crop being combusted to heat the next crop, leaving a little spare for sale or for use in CHP generation. It was not perceived as complex technology although the regulations were viewed as complex. Adoption could not be trialled on a small scale or for a short period: it is a long-term commitment involving considerable initial investment. However, the new technology could be observed in online case studies, media articles and on farms already using it.

Steps III, IV and V: Decision, Implementation and Confirmation

On-farm combustion was adopted by farmers who saw that it was financially beneficial and were prepared to take the financial risk. The technology was rejected by those who did not view it as advantageous: the smaller farms, those content with earning RHI for wood boilers, or those who were not able or willing to make the investment.

The farmers who had adopted the technology were satisfied that they had made the correct decision and advocated adoption to others. One has made further commitment by investing in CHP. No examples of discontinuance were found.

Later adoption of technology remained an option for farmers who initially selected woodfuel or gas heating. Reduced technology prices and continued high woodfuel prices could encourage later adoption. Most farmers continued to reject on-farm combustion if they had no disposal problem and no motivation to cut fuel costs.

6.1.6.2 Prospects for increased use

As litter is a by-product of the poultry rearing industry the total volume available is entirely supply driven. If consumers switch from beef, dairy and lamb to chicken, as promoted by the CCC (CCC, 2019), and demand for eggs, another protein source with a lower carbon footprint than red meat (Taylor et al., 2013) increases, then UK litter production will increase, if the increased demands are met by UK production. Expansion of the poultry industry is likely to include more of the largest poultry farms (Wasley, 2018) which are the most likely to supply litter for energy generation.

The proportion of litter available for energy will increase if demand for fertiliser falls, either as a result of changing farm practices or environmental regulations for nitrates or phosphates. Power stations sourcing litter from Y&H were fully supplied with biomass at the time of the interviews, but if the supply of litter were increased more generation capacity could be supported. If the prices offered by power stations were high enough then litter could be diverted from land-spreading to combustion, and ash used as fertiliser.

Litter is generally restricted to 15–20 % of AD plant feedstocks to avoid ammonia problems (*ADC2*), although some new AD plants have the technology to allow processing of 100 % litter (Walsh, 2016). Changes to ammonia regulations to reduce nitrous oxide (N_2O) emissions could require an increase in the quantity of litter and other manures processed by AD (CEH and Rothamsted Research, 2019), leading to either higher proportions of litter in the feedstock used, or to the potential to increase AD capacity. AD plants processing wastes, including food waste, would be unlikely to pay for litter when they are usually able to charge a gate fee for accepting their feedstocks (Anthesis, 2018). It can be concluded that the demand for litter is likely to remain at 15–20 % of farm-fed AD capacity. Prospects for the growth of the AD industry were poor at the time of the interviews (*ADC1 and ADC2*), but government support could stimulate another phase of expansion (see section 2.6.4).

Although interview data showed that on-farm combustion of litter was attractive for large farms who could fund the high capital costs, uptake was constrained by both the cost of litter-fed boilers and the limited range of technology suppliers who met EU regulations. However, maturing technology was expected by current users to result in lower boiler prices and increased uptake of on-farm combustion, especially if the cost of alternative fuels (generally wood chips and pellets) remains high.

Although combustion ash can be used as a P and K fertiliser, the lack of humus may deter combustion by farmers who do require humus (Case et al., 2017). Many farmers use woodfuel for heating their poultry sheds and have been encouraged to do so by the RHI. However, this RHI support appears to have made farmers complacent and it may be discouraging them from exploring the further fuel cost reductions available by using litter as a fuel. After the non-domestic RHI scheme ends in 2021 (see section 2.6.4) any reduction in support for woodfuel may make litter a more attractive fuel for newly constructed poultry units.

The EU litter regulations introduced in 2014 were intended to simplify on-farm combustion, but by limiting combustion to 100 % untreated litter and imposing a combustion temperature of 850 °C, the use of adapted wood fuelled boilers was prevented and the researcher found only one boiler supplier who was compliant. These regulations could continue to discourage uptake, but as the experience of adopters has been good for broiler and laying hen litter, they may not be a long-term barrier. Although laying hen litter has a lower energy content than broiler litter (Tańczuk et al., 2019; Junga et al., 2017) it is being combusted successfully and this resource should not be overlooked in the assessment of bioenergy potential. There may be the prospect of regulation change post-Brexit, but while technology is operating successfully it is unlikely that there will be sufficient appetite from technology suppliers to press for changes.

For the farmers who use contractors to clean their sheds and remove the litter, the decision on use is made by the litter merchants who sell it to power stations or farmers, and the role of these merchants in the trading of litter should be considered when assessing the supply of litter.

In summary, litter production as a by-product of poultry rearing is easy to quantify, but the volume available for energy generation was found to be constrained by the demand for fertiliser. An increase in litter supply could result from industry growth while demand could change as a result of land-spreading and storage regulation changes, demand from new power stations, growth in the AD industry or increased use of on-farm combustion. Without one or more of these changes the use of litter is unlikely to increase significantly. The supply of litter, barriers to its use, and the changes that could remove these barriers were well understood, so it was decided that further research into policies to overcome these barriers would not be carried out.

6.2 Energy crop interviews

This section contains the results and analysis of the twelve energy crop stakeholder interviews (see **Table 4.3** for details of the interviewees). The researcher also attended a Farm walk (Terravesta and CLA, 2019) and discussed attitudes to planting miscanthus with farmers who already grew the crop, and those who were interested in planting in future. These discussions confirmed the findings of the interviews.

The five most important themes identified from analysing the interview data are discussed, together with regional factors affecting energy crop cultivation, and the interviewees views on the prospects for energy crop cultivation. Then the barriers to, and drivers for, energy crop cultivation are listed and the key barriers discussed. The Rogers' DOI theory is used to structure a discussion of the decision-making process and conclusions are drawn.

6.2.1 Results of thematic analysis

The most important themes identified from thematic analysis of the interview data were:

1. Experience of annual crops has been better than for perennial crops
2. Contracts and finances drive the planting choices of farmers
3. Current agricultural policies discourage the cultivation of PECs
4. Brexit was delaying decision making and was a serious concern for some farmers
5. Some negative attitudes to energy crops persist.

These themes are described in the following sections, drawing directly from the interview data.

6.2.1.1 Experience of annual and perennial energy crops

6.2.1.1.1 Experience of growing willow

Willow growers interviewed have had some bad experiences and many have abandoned the crop, and reverted to growing traditional food crops. The early planting of willow in 1998 was for the ARBRE project (see section 3.4), which was promoted through the NFU, CLA (Country

Land and Business Association), and at roadshows, primarily as a low input crop of interest to farmers nearing retirement. At that time grants were available to cover all planting costs and contracts offered payments per acre of willow grown plus payments at harvest. The ARBRE project collapsed leaving the willow farmers with no market until they collectively negotiated contracts with Drax Power Station. Later, farmers planted willow specifically for Drax, under long-term contracts via third parties.

The willow was slow to establish and needed more inputs than expected: some fertiliser, weed control and insecticide (to control willow beetle infestation) (*AF2, AF5*). Harvesting was a problem for all the growers with *AF1* finding that the heavy willow harvester sank further each year. Once established the willow cropped well, but harvest was not at a convenient time for all farmers:

> *' It's also a busy time for me, spraying and fertilising, so with both crops I ended up having to get people in to help me out and basically that turned out over time to be the profit margin of the crops. ' AF1.*

Drax cancelled all willow contracts in 2016, preferring to rely instead on importing wood pellets. This once again left farmers without a customer:

> *'It was a huge blow and… it reinforced all the naysayers.' AF5.*

The Iggesund paper mill In Workington (see **Box 2** below) is now the only large customer for willow in the north and west of Y&H. Farmers further south have no large customers, so *AF1* was left with no contract:

> *'We had a crop with no market, so we've still got a mountain of willow on the farm sitting there, rotting away, so it was all a bit of a disaster really.',*

and he questioned the wisdom of his initial decision to invest.

AF5 found that freshly harvested willow was a wet wood which required either special combustion technology that can cope with this high moisture content, or drying before combustion. The biomass boilers commonly used for woodfuel in the UK are not able to cope with willow. He found that his biomass boiler configured to be eligible for RHI was unable to combust wet willow on the farm:

> *'So that was another mistake we went down which was not to spec for our weather...If I had had a really good Austrian boiler that could have used wet fuel, had a preheating system in there, I would probably use my own willow.'.*

It was concluded that there is currently little scope for use of willow on UK farms.

Although willow has a reputation for being tricky and expensive to remove, and has a reputation for damaging drains, no long-term damage to the land or excessive drain damage was experienced by the interviewees.

Box 2: Iggesund Mill, Workington, Cumbria

Iggesund, a Swedish pulp manufacturer, produces card and packaging materials from sustainably sourced wood (Iggesund, 2019). In 2013 their Workington mill installed a 50 MWe, 30 MWth CHP plant (AF Consult, 2019) at a cost of £ 108 M. It is fuelled by 500,000 tonnes per annum of biomass, including willow grown on Iggesund's own land, and on farms in Cumbria and neighbouring counties. Iggesund set up the '*Grow Your Own Income*' scheme to encourage farmers to plant willow, and ensure a supply for the mill. Planting is particularly encouraged on wetter unproductive ground where it provides some protection against flooding and does not compete with food production. Iggesund already operated a harvesting and transporting system for their timber, so had the infrastructure and skills to set up a willow supply chain. Iggesund pays for transporting biomass and offers index-linked 22 year contracts (Iggesund, 2016). The plant is one of the largest users of Biomass in the UK: the total useful energy output of 80 MW is higher than the Brigg REP power station (40 MWe) (BWSC, 2021) or any of the UK straw-fed power stations.

6.2.1.1.2 Experience of growing miscanthus

Miscanthus growers also had some bad experiences. From 1998 onwards it was promoted by companies supplying Drax, and many farmers were recruited through adverts for contracts in the local press, e.g. The Yorkshire Post (2005). Some farmers were contacted by salesmen and others heard about the new crop from fellow farmers. With grant schemes available to cover the cost of planting and five-year index-linked contracts available, many farmers signed up:

> *'It's my dad's side, but it must have been quite attractive for him to go into it, he's usually quite reticent about stuff like that.' AF1.*

The contracts were arranged by a third party:

> *'they brought their own problems because they were a couple of guys from London who tried to pull the wool over our eyes ... they thought they could come north and take most of the grants that the Government were offering and pay us very little, so it was all quite difficult in the first few years.' AF1.*

Miscanthus was difficult to establish and the quality of the early rhizomes was mixed: resulting in the need for replanting on some farms. The first harvests were later than expected, with lower yields than predicted, and had moisture contents which were higher than the power stations wanted. Miscanthus growers lost confidence. The third party arranging the contracts collapsed in 2009 but growers found new contracts with Drax. When Drax ceased using local biomass in 2016 the farmers' contracts with Drax were taken over by Terravesta[5], but confidence in the sector took another blow.

Three of the farmers interviewed had abandoned growing miscanthus. The main reasons given for discontinuance were failing to find a buyer and deciding not to renew at the end of a contract, but recovery in the price of wheat was another key factor:

> *'When we started with miscanthus, wheat was at £65 – 70 per tonne, and when we finished with miscanthus wheat was at £110 per tonne, £120 per tonne… so it was just a financial decision.' AF1.*

After removing miscanthus one farmer found that the soil had been improved, but another found no impact.

Even for the early planters the crop did establish well after some initial problems. The interviewees felt that the newer strains and planting techniques available would result in better establishment than early adopters experienced. *AF3* thought that with hindsight they had suffered from being early adopters and they *'were a little bit too soon'* in growing the crop.

Miscanthus is still attractive to farmers who have specific requirements of a crop, and contracts for planting in 2019 were available at the time of the interviews. Although it was originally targeted at marginal lands it can be successful on areas of land which are expensive or difficult to cultivate for a variety of reasons. This includes fields which are far from the main farm, have difficult (heavy or very light) soil, mixed soil types, or are awkwardly shaped with

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[5] Terravesta is a Lincolnshire based company which supplies miscanthus rhizomes and arranges contracts for miscanthus supply.

hard-to-access corners. Miscanthus, which only needs harvesting once a year leaves the farmers with more time to concentrate their effort on the more productive land:

> *'Plant miscanthus on the 10 % of your worst land then you should focus on the other 90 % and the miscanthus will look after itself.' LM1.*

This is now one of the main attractions for farmers considering growing miscanthus as a part of a diversified farm plan.

6.2.1.1.3 Experience of annual energy crops

The farmers interviewed had good experiences of growing annual energy crops. Maize was very popular with farmers near AD plants, who had light soils, and were far enough south to grow it (Yorkshire is currently at the northern limit). They signed up to annual contracts with local AD plants. Maize was viewed as a good addition to an arable rotation, which sometimes allowed an extra crop where there was previously a gap in the rotation. Maize also helps in the eradication of black-grass[6] which is a big problem for arable farmers. Some farmers viewed maize as a tricky crop to grow before they planted it, but with attention to detail, most can grow it successfully. Maize is very attractive to both AD plants and farmers:

> *'Maize is the prime energy crop because of its energy yield, … it fits nicely into the farmers' rotations…it is relatively easy to manage, most of the growing can be done under contract. So I can understand why it is attractive to them.' ADC2.*

It can also use the digestate from AD plants:

> *'Maize is very efficient in terms of using organic matter and digestate from the process itself, so it is genuinely a circular relationship.'* ADC2.

Growing grass did not feature strongly in literature on energy crops and was not specifically included in the original interview questions. However, farmers who supplied maize to AD plants also talked about planting other crops such as grass, wheat, and hybrid rye for AD. Planting grass leys[7] (AHDB, 2018b) was a popular option for arable farmers e.g. as one reflected on his decision to plant grass leys:

'*Yes, it was a good decision. Yes, it was an easy decision.' AF2*.

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[6] Black-grass (Alopecurus myosuroides) is a herbicide-resistant weed which reduces cereal yields the UK.

[7] Leys are fields planted with grass for between one and five years as a part of an arable rotation.

Grass, wheat, and hybrid rye were all popular crops to grow in a rotation to supply a good, varied diet for an AD plant. Grass leys were particularly suitable on heavy land prone to black-grass. Sugar beet was found to be too difficult to digest, but pulp from sugar factories was more popular. Wheat is grown in Y&H for biofuels and it was felt that the demand from refineries had boosted the wheat price locally.

6.2.1.2 Contracts and finances drive the planting choices

The availability of contracts for perennial and annual energy crops drives the decision to plant them. Although farmers planted PECs when contracts were being strongly marketed, and they were financially attractive, the loss of contracts, and strong competition from other crops, led to significant areas of the crop being removed. The remaining willow in Y&H is grown under contract for Iggesund's, and miscanthus is grown for Brigg (Lincolnshire), and Snetterton (Norfolk) power stations. In contrast annual crops have been easy choices for farmers because of the availability of annual contracts directly with local AD plants. Farmers will not make speculative plantings of PECs: they will only plant when a financially attractive long-term contract is in place.

Despite having had bad experiences with PECs, farmers would not rule out planting them again *if* there were attractive contracts available. Although the farmers who had abandoned the crops initially said that they were unwilling to replant, on reflection they all said that they would consider growing them again, if the price was right and they were happy with the terms of the contracts. These reactions to replanting were typical:

> *'No, no. Unless it came up with a substantially different contract. Then I would reconsider it…. You never say never but you can set your parameters. It has to be financially viable.' AF3,*

and

> *'If the price was right I would look at it, but I would have to see some kind of guarantees behind the contracts. I firmly believe that the contract should come directly from the end user rather than a third party.' AF2.*

One of the most common reasons given for abandoning energy crops was that they could get a better price for growing cereals, particularly wheat. Miscanthus and willow were attractive when cereal prices were low, but lost their advantage as cereal prices recovered. Ultimately, the decision on what to plant is always financial: if the contract on offer is attractive enough compared with other land uses, and other crops, some farmers will consider planting PECs:

> *'I think there is bound to be a price where it gets people looking at it again…Yes it's always down to price.' AF1.*

All the farmers were concerned about the environment on their farms. Most of them took part in environmental schemes such as planting or preserving hedges, creating ponds, or protecting ings[8] land. They try to balance financial and environmental considerations in decision making, but their farming activities always need to be financially viable. Most farmers expected the grants for environmental schemes to be more profitable than alternative land uses e.g.

> *'if there's payment for pollen mixtures and wild bird food over the winter and things like that, if the payments are right and such like, I wouldn't have a problem in doing them at all.' MF1.*

6.2.1.3 Current agricultural policies discourage planting of PECs

Not only were there no financial incentives or grants supporting PECs, but farmers were discouraged from planting them by the agricultural policies in place at the time of the interviews. Without planting grants, the upfront cost of planting, and the lack of income for three or four years are big barriers to planting miscanthus and willow: '100 % they are less willing to grow miscanthus now that the grants are gone.' LM1.

The agricultural industry was heavily subsidised in the EU, including the UK at the time of the research. In 2018 the CAP subsidies made up anywhere from 50–80 % of a UK farmer's income (Downing and Coe, 2018), see **Box 3** below for details of farm payments and agri-environmental schemes. Farmers planting PECs lost a proportion of their farm payments as they did not qualify for *greening* payments, although annual energy crops and grass leys did. This loss of income for PECs was a significant penalty and discouraged planting.

The Government did not recognise the positive environmental impact of energy crops and had excluded them from agri-environmental schemes, although farmers felt that the perennial crops were good for the environment and were better for biodiversity than some of the crops supported by stewardship schemes. Willow, undisturbed for three years, is a suitable habitat for birds, mammals, and insects, improves water quality, reduces soil erosion and run off, and improves biodiversity. Miscanthus is a good habitat for song birds and ground nesting birds.

[8] Water meadows and marshes on flood plains.

Box 3: Farm payments

In 2019/20 two sources of farm subsidy were available from the EU Common Agricultural Policy (CAP): the Basic Payment Scheme (BPS) and agri-environmental funding (often referred to as stewardship).

The EU Basic Payment Scheme was the main rural payment available to English Farmers (DEFRA, 2018a). All agricultural land was eligible except woodlands, Christmas trees, tracks, buildings, yards, and solar farms. Payments could be claimed by people with 'land at their disposal': including farmers who own their land and tenant farmers. (The Andersons Centre, 2018a). 30 % of a claimant's total BPS payment was conditional on complying with the *greening* rules which cover three main requirements: crop diversification, ecological focus areas (EFA) and retention of permanent pasture. Crop diversification required arable farms to implement a rotation including a minimum of two or three different crops, depending on farm size. EFA required larger farms to devote 5 % of arable land to ecological uses including hedgerows, fallow land, field margins, and nitrogen fixing crops (The Andersons Centre, 2018b). A wide range of crops were approved for inclusion in rotations to meet the BPS greening rules (Rural Payments Agency, 2018a) including: arable crops (including maize), vegetables, tobacco, herbs, and flowers. Crops classified as permanent were ineligible: this covered miscanthus, willow, reed canary grass and most fruits and nuts. Miscanthus was added to the list of eligible crops in 2018 (European Union, 2018) and the greening regulations are to be removed in 2021 (DEFRA, 2020d).

Agri-environmental schemes (countryside stewardship) were available to fund farmers, landowners, foresters, and land managers to improve the environment (DEFRA, 2019a). Annual payments were received in return for promoting biodiversity, improving water quality and other environmentally beneficial schemes, e.g. growing nectar rich wild flower mixes. Since September 2018 woodland planting and woodland management has been included in stewardship but delivered by the Forestry Commission (DEFRA et al., 2018).

The interviewees felt that greater perennial planting could be encouraged by more supportive policies:

> '*the Government acknowledging miscanthus as a sustainable crop would be good, …. I'm not asking for planting grants again or subsidies for it … I think it is fundamental that miscanthus stands upon its own two feet, but obviously it would be brilliant if the Government were to acknowledge it as a positive crop.*' *MISCS.*

Lobbying the Government to support miscanthus has had no success. Farmers thought that the Government was influenced too much by environmental charities and one highlighted the impact of press coverage of energy crops, in particular the impact of the RSPB report on wood burning (RSPB, 2011):

> *'That has been massively damaging… I think that virtually killed it.' AF5.*

Agroforestry is of interest to some farmers but is not supported by the Government. It falls between forestry and agriculture governance, qualifying for support from neither. This will be covered in more detail in the analysis of woodland planting in section 6.3.1.5 and **Box 5**.

6.2.1.4 Brexit was delaying decision making

Although Brexit was not a topic in the initial interview script, it was clear from the first interview that this was a topic that was worrying the interviewees, and it was covered in all subsequent interviews. The interviews were carried out from October 2018 to January 2019. During this time there was considerable uncertainty over the way in which the UK would exit the EU and the effect that this would have on farmers and landowners. During early interviews the interviewees were confident that the UK would leave the EU on 29 March 2019 under the terms of the withdrawal agreement. As time went on there was growing uncertainty and there was a real fear among some of the interviewees of leaving the EU without a deal (see **Box 4** for the state of Brexit negotiations during the interview period).

Many interviewees were concerned about the impact of changes to tariffs, and from the weakening of the Pound against the Euro increasing machinery costs. Most farmers were generally in favour of Brexit because it would allow the reformation of agricultural subsidies, putting greater emphasis on delivering environmental benefits. However, there was fear that a '*no-deal Brexit'* would result in tariffs on exports to the EU, making their goods impossible to sell there, and as a consequence, UK prices would fall.

Box 4: Brexit: The departure of the UK from the EU

Following the vote for the UK to leave the EU in the referendum on 26th June 2016, the Prime Minister, Teresa May, triggered Article 50 of the Treaty on European Union on 29 March 2017, giving notice that the UK would leave on 29 March 2019. The withdrawal agreement was signed on 14 November 2018 by the UK and EU negotiating teams. A *meaningful vote* in Parliament on the negotiated terms of withdrawal was planned for 11 December 2018 but this vote was pulled when it became clear that the Government would be defeated. Mrs May faced a vote of no confidence in her leadership of the Conservative party, which she won. The meaningful vote was held on 15 January 2019, and, following a defeat for the Government, the opposition tabled a motion of no confidence in the Government, which was defeated. Negotiations were under way with other parties in late January 2019, but fear of a *no-deal* Brexit was growing (Walker, 2019).

The UK Government pledged to maintain the same funding for agriculture as previously distributed under the CAP, until the end of the Parliament, which was expected to be in 2022 (Downing and Coe, 2018). In 2018/19 the understanding was that when the UK left the EU, the Basic Payment Scheme would be phased out in a transition period, and replaced by a policy which would reward the delivery of 'public goods' by farmers (The Andersons Centre, 2018a). This new land management plan, the Environmental Land Management (ELM) scheme, would replace BPS and stewardship, and would also include forestry (HM Government, 2018).

The UK officially left the EU on 31 January 2020, but a transition period followed, ending on 31 December 2020, during which trade continued as before. It was not until 24 December 2020 that a trade treaty was agreed between the UK and the EU. The deal maintained tariff-free access to the EU market for UK agricultural exports, and was tentatively welcomed by the CLA and NFU (Tasker, 2020).

Because of the uncertainty, farmers were delaying making major decisions, particularly on environmental schemes, in case the post-Brexit incentives were better than those already available:

> *'At this moment of course everybody's minds are focussed on Brexit… So it is a wait and see game just at the minute.' MF1.*

And

> *'I think most farmers will be holding off at the moment doing anything off their own bat, waiting to see after Brexit I guess.' AF1.*

Thus, uncertainty over Brexit was reducing the activities which the new agricultural policy is intended to promote.

6.2.1.5 Some negative attitudes to energy crops persist

Among some arable farmers the perception persists that energy crops are *'a waste of good farmland'*, *PF4*. Even those who were open to new innovations in general had some negative perceptions of energy crops. Farmers planting PECs had faced scepticism in the early days:

> *'A lot of people questioned it but my decision was based on the quality of the land that we had and the output I knew that we could get from it.' AF4.*

Farmers are aware of the problems that have been experienced by energy crop growers and this has fuelled their own scepticism e.g. one interviewee taking over land planted with miscanthus admitted that:

> *'I didn't really do any figures on the miscanthus, to be fair, we are arable farmers so it was always going to come out and be put back into arable crop rotation…' AF2.*

Planting willow was viewed as a bigger change to normal farm practices than planting miscanthus, and a longer-term commitment:

> *'Growing a tree is a different mindset and approach. While miscanthus is a very tall energy crop, it is, in essence a grass, and can be removed relatively easily within a cropping year. … Whereas willow is a lot more difficult and it is a different mindset: growing a field of trees compared to a grass.' LM1.*

The fear that willow would damage farm drains was widespread:

> *'My reservation was the deep roots that can damage the drains… We didn't go for that.' AF3.*

6.2.2 Regional factors

The interviewees felt that their experience of cultivating annual and PECs were similar to those of farmers throughout England. There were no regional grants or incentives, and the factors in deciding whether to plant energy crops would be the same throughout the country. The only geographical constraint was that Yorkshire is on the northern limit for growing maize. However, the regional demand for biomass has determined the level of planting, and the interviewees had experience of biomass production for ARBRE, and Drax, that farmers in other regions will not have had, and they now have markets that are not present in some parts of the UK.

6.2.3 Prospects for energy crops

Farmers thought that the planting and harvesting techniques of PECs had improved over time and that the strains of crops available were better than those planted originally. However, while the price of wheat remains high, the Government fails to support energy crops, and few contracts are available, the area planted is unlikely to increase significantly. Annual crops were expected to remain popular for AD but growth in the sector was not expected.

6.2.4 Drivers and barriers for energy crop planting

The key drivers of, and barriers to, energy crop planting, identified from interview data are summarised in **Table 6.3**.

The main barriers to PEC cultivation: the lack of contracts and markets, the inability to compete with cereal prices, unsupportive government policy, and negative attitudes to energy crops; could all be overcome to allow a significant increase in the area of planting. These findings confirmed the previous analyses of barriers discussed in section 3.4.2; however, there are some differences in the relative importance of the barriers. The findings also suggest, as McCormick and Kåberger (2007) previously found, that there are no intrinsic technical issues with cultivating PECs that cannot be overcome. The most important barriers are discussed below.

Table 6.3 Drivers and barriers for energy crop planting

Perennial crops drivers
Long term contracts for perennial crops give income security to farmers
Require low input of both effort and fertiliser
Low input crops suit difficult to cultivate land
Farmers will plant if the price and contract are right
Perennial crops barriers
There are few markets for willow or miscanthus
Cereal crop prices currently make miscanthus and willow financially unattractive
Government policy: PECs were not eligible for greening farm payments or stewardship schemes and no grants are available for planting
Negative perceptions of energy crops persist
Annual crops drivers
Grass and maize fit in well with farms' crop rotations and help eradicate black-grass
Attractive contracts from AD plants are available
Annual crops barriers
Attitude that farms should grow food not energy crops

6.2.4.1 Lack of markets and contracts

PEC production is driven purely by demand for the biomass, and is constrained by the competing demand for land use from other agricultural and non-agricultural activities. New demand could be created from new power stations or from industrial, municipal or small-scale heat and/or power users. Contracts with these new users would have to be attractive enough to provide an advantage over growing other crops and compensate growers for additional risk, i.e. long-term contracts with reliable customers offering competitive, guaranteed and possibly indexed linked prices. To be able to provide such contracts these large biomass users would have to be steered into selecting energy crops by legislation, supported by incentives (such as the Contracts for Difference scheme (CfD), RHI or a successor to the RHI scheme).

The initial cost of planting and impact of loss of income for three or four years could be reduced by the reintroduction of planting grants from the Government or from sufficiently attractive contract terms (possibly subsidised indirectly by the Government).

The lack of energy crop markets and supply chains had been identified previously as a barrier (Adams et al., 2011; Lindegaard, 2017; Burgess et al., 2012). Sherrington et al. (2008) suggested that uncertain returns from novel crops could deter their cultivation. This research found that not only were markets important but that farmers simply will not make speculative plantings of PECs: they will only plant when a financially attractive long-term contract is in place. In contrast, cereal crops with well-established markets, are planted by farmers willing to grow the commodities for an uncertain price, (although they can be grown for a contract too, to reduce the risk to both farmer and buyer e.g. for Waburtons bakers (Jones, 2019)). A farmer may wish to balance their risk by growing some PECs with a guaranteed price per tonne to provide secure long-term income: even if they hope to get a higher price for other crops. Although McCalmont (2017) and Mitchell (2004) both discuss a '*chicken and egg*' problem of neither generators nor suppliers being prepared to act first, it seems from this research that the farmers will not plant without a secure market and so the deadlock has to be broken by generators providing supply contracts.

Even when a market is available farmers may still not be willing to plant PECS, e.g. Warren et al. (2016) found that farmers near Lockerbie were still reluctant to plant willow, even though there was a local market, as they viewed it as incompatible with their practices, alien to their way of life, and a high-risk long-term commitment. The opportunity to make a profit from growing PECS was insufficient motivation to overcome the influence of social norms, personal values, and aesthetic judgements. Farmers' reactions to incentives are not always economically rational; many other factors may be more important in decision-making (OECD, 2012; Collier et al., 2010).

The role of '*middlemen*' was something that farmers were very wary of: preferring to have clear contacts and supply chains. Power station tours for farmers may be effective marketing tools for companies offering miscanthus crop contracts because it allows the farmers to see the full supply chain and build confidence in the contract. Contracts directly with biomass users are desirable from a farmer's perspective, although they may not be feasible in practice.

Local heat markets had been suggested as possible stable markets for PECs (Adams and Lindegaard, 2016; Burgess et al., 2012), but small scale demand for energy crops (to fuel boilers for farms, hotels, and schools in areas off the gas grid) has not developed in Y&H. None of the growers of energy crops had boilers that could use it, although several had wood fuelled boilers. The RHI has successfully driven the use of woodfuel in these small-scale applications but energy crops, which need different technology to meet emissions regulations, have failed to compete with wood as a fuel. If woodfuel prices remain high, then farms without their own wood supply may investigate the use of willow or miscanthus boilers. This could result in competition with the woodfuel market. The preference for using biomass for large scale power generation (CCC, 2018a; Energy Technologies Institute, 2018) also makes small-scale use an unlikely source of demand in future.

Although energy crops cannot currently compete with cereal crops there will be a price at which they could become competitive, even for farmers who have had bad experiences in the past. This price will be determined by many factors including: the potential profit from cereal crop cultivation and other land uses, how valuable the security of a long-term contract is to farmers, the availability of farm subsidies, and rewards available for stewardship schemes. Reforms to UK farm policies are expected to remove subsidies for growing cereal crops, making them less attractive than currently.

6.2.4.2 Government policy: farm payments and subsidies

A lack of consistent government policy has previously been identified as a barrier to energy crop cultivation (Adams and Lindegaard, 2016; Adams et al., 2011; Foxon et al., 2005), and the interview data showed that Government agricultural policy is still a barrier to cultivation: not just as a result of inconsistency, but the removal of subsidies and the exclusion of PECs from farm payments has almost killed the cultivation of energy crops in the UK. This lack of support for energy crops was thought by interviewees to be a result of the Government succumbing to pressure from charities and pressure groups in a bioenergy backlash e.g. RSPB (2012). It can be concluded from the interviews that if the UK is to plant anywhere near the level of energy crops proposed by the CCC for BECCS, then government policy will need radical reform and anti-biomass pressure will have to be resisted. The post-Brexit ELM scheme will need to end the penalisation of energy crop cultivation and planting grants may be needed.

6.2.4.3 Negative attitudes to energy crops

Some negative attitudes to PECs persist including: the view that farmers should grow food not industrial crops (*AF2*), fears of the impact of willow on field drains (*AF3)*, and the reluctance to commit to the long-term land use change that perennial crops require (*LM1*). The popularity of annual energy crops with interviewees shows that many farmers *are* happy to grow crops for energy: the attitude that farmers should grow crops for food not energy has not prevented the cultivation of AD feedstocks, so in future it may not prevent the increased adoption of energy crops. However, growing annual energy crops is very like growing traditional food and fodder crops. It is a bigger cultural and technical change to plant a perennial crop like miscanthus and bigger still to plant willow which was viewed as more like forestry (*LM1*). It could be argued that the change of practice, rather than disapproval of non-food crops, is preventing planting of PECs, and growing annual energy crops could pave the way towards the acceptance of energy crops as a normal part of farming. If this is the case miscanthus may initially be a far more attractive crop to most farmers than willow which is less familiar.

6.2.5 Exploiting drivers

The role that drivers could play in the promotion of energy crop cultivation should also be considered as well as considering the removal of barriers. In particular, long-term guarantees of income could be attractive post-Brexit, when changes to farm payments may cause uncertainty in farming.

6.2.6 Discussion and conclusions

The analysis of the interview data has identified the barriers to, and drivers for, greater use of energy crop production, and these were discussed above in section 6.2.4. The steps of the DOI innovation-decision process (Rogers, 2003, p170) are now used to structure a discussion of the findings from the energy crop interviews, to understand the factors influencing the farmers' decision making when considering adopting energy crops, and understand how the barriers to cultivation could be overcome.

6.2.6.1 Analysis of the adoption of perennial and annual energy crops

Prior Conditions

The previous practice for most of the energy crop interviewees was to grow cereal crops or animal fodder, or to graze livestock on their land. This was also the norm for their social system (the other farmers they knew). When cereal prices fell farmers felt the need for more profitable crops, and farmers near retirement, or with difficult land, wanted low maintenance crops.

Farmers always want to maximise farm profits and can sometimes achieve this by diversifying their activities into new ventures, agricultural practices, or crops. Some of the interviewees had invested in diversifications such as solar power and tourist lets, and were open to the new ideas at the time of the interviews e.g. agroforestry, and minimum till cultivation, showing varying degrees of innovativeness. Many farms were owned by partnerships of more than one generation of a family and so if a new practice was to be adopted, it must have been supported by all the partners. It was not always the younger generations who were most enthusiastic about adopting PECs.

Communication Channels

The farmers drew information from a range of communication channels. They read the general farming press such as *Farmers Weekly* or *Farmers Guardian*, and some more specialist publications e.g. *Crops, Acres* or *Arable Farmer*. Most were members of the Country Land and Business Association (CLA) or the NFU, and they attended agricultural shows, farm walks/visits and some used social media. The farmers employed advisors, such as agronomists, and advisors on fertiliser, insecticide, and herbicide use, but also gathered information from informal networks of family, friends, neighbours, and salesmen.

Step I: Knowledge

In the knowledge step farmers became aware of the innovation from their information channels (e.g. The Yorkshire Post, farming press, and salesmen), paying particular attention to data relevant to their specific needs and current conditions. The farms (decision making units) that planted energy crops could be characterised as medium to large, family-owned arable farms. The environment was important to the farmers, but innovations had to be financially attractive as well as environmentally favourable.

Step II: Persuasion

During this step farmers formed favourable or unfavourable attitudes to energy crops, and the key factor in shaping these attitudes was their advantage relative to other crops. When PECS were first promoted, they offered a long term guaranteed income which was higher than available from wheat, for growing crops that required low inputs of insecticides, pesticides, and fertilisers, and were supported by government planting grants. Annual energy crops were grown when AD plants were offering attractive prices for one-year contracts for a crop that was relatively easy to grow.

Perennial crops were promoted as being compatible with arable farm schedules: requiring little input other than harvesting in winter or spring when farm workloads were expected to be low. Maize and grass were expected to fit in well with farm rotations and suppressed black-grass and so were perceived as compatible with the normal operation of farms. All energy crops were viewed by some farmers as being incompatible with traditional farming values and practices as food producers.

Energy crops were not viewed as very complex initially, but there were a number of issues with establishment, harvesting, and drainage which later resulted in them being perceived as difficult crops. Maize was viewed as a new crop that may need careful cultivation but confidence soon grew among growers.

PECs could be trialled with small areas of plantings (subject to contract and grant minima) but did require a long-term commitment. Maize and grass were easy to remove, miscanthus more difficult and willow was viewed as more permanent.

There were plenty of opportunities to observe all the crops even for early adopters. Farm walks and power station visits were good ways for farmers to see the whole supply chain in operation.

Steps III and IV: Decision and implementation

Farmers decided to plant willow and miscanthus when the crops were suitable for their farms and the contracts were attractive. Deciding to grow crops for an AD plant was an easier decision as the risks were lower: the contracts shorter and the divergence from normal farming process smaller. Many farmers did not adopt energy crops: instead they continued growing only traditional crops

Later adoption remained an option for farmers whose priorities had changed, or who had taken on new land that was suited to energy crops.

Annual energy crop cultivation for AD has been adopted at a much faster rate than PEC cultivation. Although farm AD only became well established between 2014 and 2016, following incentives taking effect in 2010 (Savilles, 2018), the cultivation of annual crops was already perceived as normal practice by interviewees: whereas perennial crops were far from reaching this level of acceptance despite promotion of the crops starting in the 1990s and grants being first introduced in 2000. According to the DOI, the rate of adoption in a social system is primarily determined by the five factors comprising the perceived characteristics of the innovation (advantage, compatibility, complexity, trialability and observability) and the efforts of change agents (Rogers, 2003, p. 221). Clearly the perceived advantages of annual energy crops were much greater than those of PECs. The rate of adoption of PECs increased initially when they were being actively marketed, and grants were available, but declined when the contracts were no longer widely promoted.

Using the DOI categories of adopter (Rogers, 2003, p. 221) all the early planters of willow or miscanthus (AF1, AF3, AF5, and LM1) could be categorised as '*early adopters'*: they were among the first UK planters who adopted the innovation despite widespread scepticism from other members of their social system. By the time AF4 planted miscanthus diffusion had progressed and he displayed the characteristics of an '*early majority adopter*' who had seen some of the most innovative members of his social system pioneer the practice. The farmers on the miscanthus farm walk in 2019, considering planting, and forming an opinion of the crop, could also be classed as potential '*early majority adopters'*, as although the innovation was well understood and easily observable, uptake was still low.

Step V: Confirmation

PECs were still being grown by the farmers who had been able to find contracts and still found that the crops suited their farms' conditions. Grass and maize growers have been very happy with their crops and continued to plant them in most years. Many PEC growers discontinued adoption when their relative advantage over other crops diminished: they removed the crops when the promised yield was not delivered, when contracts were lost or came to an end, when they failed to fit in with farming routines, or when cereal prices recovered. The main problems with both willow and miscanthus were not the crops themselves, but the contracts, markets, and financial factors.

Most farmers continue to reject PECs because they fail to deliver an advantage that outweighs the risk of adoption, and negative perceptions persist even among farmers who are open to other new innovations. Re-adoption remains an option for PECs, and the farmers who have discontinued PEC cultivation all said that they would grow them again if the contracts were right. These early adopters could play an important role in rebuilding confidence in the crops. They are some of the most innovative farmers who are likely to be influential in their social networks, and if they were to grow PECs again this could change attitudes among less innovative farmers.

Most farmers growing crops for AD have continued to grow them. Some have chosen not to grow maize in a particular year, but will grow it again: they did not view this as abandoning the crop.

6.2.6.2 Conclusions

The interview results showed that PECs have suffered from a combination of lack of demand, competition from more profitable crops, and from agricultural policies which discourage their planting. In Y&H the failure of the ARBRE project, was followed by Drax cancelling local biomass contracts (finding it easier to source wood from the US) (Mawhood et al., 2015), and small scale combustion of willow and miscanthus has not developed: leaving very limited markets. These factors continue to limit the area of PECs grown in the region, with wheat prices reaching £200 per tonne in May 2021 (Farmers Weekly, 2021).

In contrast, the popularity of annual energy crops for AD has risen because of attractive contracts for growing crops which fit well into arable rotations, and do not incur the loss of farm payments. The cultivation of AD crops is very similar to that of traditional arable farming crops, whereas PECs need a 15–20 year commitment. Adopting the annual crops is a much smaller and easier step for farmers to take than adopting perennial crops. The cultivation of annual energy crops will be constrained by the demand from the AD industry, and at the time of the interviews further significant growth in numbers of farm-fed AD plants was not expected. Demand is also constrained by the RHI regulations limiting energy crop use to 50 % of feedstocks for newer plants.

Although maize for AD is now reported separately from fodder maize in UK farm statistics, grass is not separated from fodder silage, so the popularity of grass for AD is not apparent in the UK farming statistics (DEFRA, 2017d). Grass could be overlooked as an energy crop but it has the same advantages as maize, while being a more traditional farming practice, making adoption an even easier easy decision for farmers. The success of AD crops may help to overcome the cultural reservations that farmers have about growing non-food crops, and could be a step towards the acceptance of PECs.

Although annual energy crops are currently more popular than PECs, investment to create demand for PECs and changes to government agricultural policy could reverse the situation. This research found that even the farmers who have had bad experiences in the past would consider replanting if the price and the contract terms were right, and the attitudes of these farmers could be important in rebuilding confidence in the crops. There are still situations where PECs are an attractive option for farmers, as the current growers who were interviewed confirmed. The fact that some PECs are still being grown and new plantings made, despite all the current barriers, is encouraging for their future.

A comparison of the key themes of energy crop and woodland planting can be found in section 6.4. The analysis of the interviews identified some suggestions for how the barriers can be overcome. These suggestions, together with proposals from other sources, were analysed in the Policy Delphi and the results can be found in Chapter 7.

6.3 Woodland interviews

This section contains the results and analysis of the of 25 woodland interviews which were held with: eight farmers, three owners of large estates, an owner of a small area of land, six foresters (FC, private and local authority), a charity landowner, a utility landowner, a woodland advisor, a woodland researcher, a wood chip supplier, a member of a local environmental group, and a forest trade representative (see **Table 4.3** for details of the interviewees).

The results of thematic analysis of interview data are discussed, including the applicability of these results to the rest of the UK, the interviewees views on the future prospect for woodland planting and management, and the barriers to, and drivers for, woodland creation. The DOI framework is used to structure a discussion of landowners’ attitudes to creating new woodlands. Recent changes to woodland management uptake are discussed, and conclusions are drawn from the woodland interviews.

6.3.1 Themes identified

The main themes identified from the interview data were

1. Attitudes to planting vary significantly between types of landowner
2. There are many factors discouraging tree planting
3. Pests are a significant problem for woodland owners

4. Foresters think that timber production is being overlooked
5. Government policy is not effective in driving tree planting
6. The Northern Forest could drive significant planting
7. The division between forestry and farming is starting to breakdown
8. Woodland management levels are increasing
9. RHI has created a market for woodfuel and encouraged management.

These are discussed individually below.

6.3.1.1 Attitudes to planting vary significantly between types of landowner

6.3.1.1.1 Farmers and owners of small areas of land

Farmers and small landowners were keen to plant trees on a small scale, up to about 5 ha per planting. There was little interest in larger scale plantings, but some farmers had made a series of small plantings, or were interested in adding to existing woodland areas. They planted woodland to improve the appearance of their farm, to diversify farm activities, and to provide a variety of benefits including: cover for shooting, a supply of woodfuel for the farm, shelter belts, wildlife habitats, family recreational space, and future income.

Some farmers had replaced mature trees lost in the great storms in England in the late 1980s, while others were motivated by the threat of tree diseases such as ash dieback (Hymenoscyphus fraxineus), after earlier losses to Dutch elm disease (Ophiostoma novo-ulmi). One wanted to plant a wider range of species of trees to reduce susceptibility to disease and to improve biodiversity:

> *'At the moment ... the majority is two species: sycamore and ash... We have ash dieback already and I risk losing all of that. So I could lose half of my woodland in the next few years. So my view is let's try and get about 10 different species in for the future, and see how we go.' AF5.*

However, the farmers were aware that once trees were planted the land could not be changed back to arable:

> *'Once you have planted it with trees it's stuck in trees. You can't back out of it. And if you are a farmer thinking about what your daughter or son are going to do in the future you have locked them into a decision for the next 40 years.' FTREP.*

An unconditional felling licence with no requirement to replant is needed to remove trees, and these '*are pretty difficult to get hold of' FTREP*. This permanent change of land use was discouraging farmers from planting trees.

Although grants are available to cover the initial costs of planting and some annual maintenance, farmers lose their farm subsidies and any annual income from arable or livestock farming when they plant trees, and must wait for many years (at least 15–20) before any income can be generated. They were aware of the view that planting trees could immediately reduce the value of land, but for small plantings they were generally interested in long term benefits to the farm, and minimised possible losses by planting on less productive land. Although this is a common fear, interviewees felt that they had not decreased the value of their farm by planting trees. Plantings are often on low grade or flood prone land, but even those on good arable land have not affected the land value:

> *'I feel that the scale that we have done it, on our particular farm we have not decreased the value of the whole farm by putting woodland on it.' AF6.*

WCR described an optimum level of tree planting that would enhance the value and appearance of a farm, but above this level, a '*sweet spot*' at about 7 % by area, the value of a farm would begin to fall.

Investing in woodland was always a long-term project, and any loss in value was viewed as a short-term problem:

> *'Maybe in the short term you lose some but … you have a high value timber crop in twenty to thirty years.' EO3.*

The recent rise in timber and woodfuel prices means that trees are a valuable investment and this future income will be reflected in the land value:

> *'In simple terms they've got an alternative source of income, so it's a diversification... it's also having a savings bank account on the farm, it can sit there for 20, 30, 40 years and you don't have to harvest it in September, you can harvest it whenever you want, and cash that in when you need a cash injection on the farm.' FTREP*.

Although woodland planting is often promoted for low grade upland farmland, *WCA* thought that arable farmers may benefit more from tree planting than upland farmers. They would experience increased arable yields because of sheltering and farm warming, and the trees would produce more woodfuel than trees planted in exposed areas. This was borne out by the experience of *HF1* who planted on an elevated, exposed site, and was less satisfied with his planting than the lowland farmers. After twelve years he had poor establishment of the trees and had *'actually lost money in what I would have got in farm payments.'*

However, most farmers *have* been pleased with their tree planting, both aesthetically and financially. The comment that, by planting trees '*we have made the farm a nicer place to live and work', AF6,* was typical. When farmers plant small areas of trees the projects do not always need to be economically beneficial. The farmers were often happy to forgo income in return for improving the look of their farm and improving its biodiversity. When planting small areas of woodland there was often the attitude that they were doing it for themselves and their families:

> '*We did it for ourselves really, we like wildlife and we like trees on farms rather than a big open area, it stops wind blowing right across, so we do get some benefits from it, but it's just nice' AF1.*

Farmers with biomass boilers, who use their own wood to heat their buildings, and claim RHI, have made significant savings e.g. one has saved £6–7,000 per annum on fuel *and* received £12,000 RHI.

6.3.1.1.2 Estate owners

The estate owners interviewed all had considerable commercial forestry activities: having 500 ha, 300 ha and 400 ha of managed woodland making up 25 %, 29 % and 11 % respectively of their land. The owners with the higher proportions of planting felt that they had enough land allocated to trees: whereas *EO2*, with 11 % woodland was interested in planting more and planned to:

> *'dot the wildlife areas around the farm in the less productive bits while doing the high output farming alongside that'.*

Estate owners strike a balance between forestry, which ties up capital for the long term, and enterprises generating annual income such as agriculture, hosting events and running visitor attractions. For the estate owners, forestry is a core business.

6.3.1.1.3 Charites, utilities, and local authorities

Charities, utilities, and local authorities own a significant area of the region, and they have diverse priorities for their land, and hence different attitudes to woodland planting and management.

The employee of the historic charity was interested primarily in the historic landscape, the restoration of ancient woodland and public access, with no interest in new planting:

> *'We don't really create new woodlands, or we have not done because we tend to maintain and restore landscapes rather than create new ones.' CLO.*

They were unlikely to plant trees on land that had not been forest in recent centuries and were not influenced by grants although they would take any grants available:

> *'We work out what is best and then if we find there is finance or grant aid available to deliver what was right then we will take it.' CLO,*

but grants had no influence on the decisions that they made on tree planting. It is worth noting that since the interviews took place attitudes have changed significantly (see **Box 7**).

The environmental charity whose staff were interviewed prioritised the preservation of existing habitats and native broadleaved tree planting over timber production or carbon sequestration, for plantings on their own land, or in projects they support:

> *'We are obviously always promoting mixed native broadleaved woodland. UK sourced and grown.' WCA.*

Utility landowners prioritise water quality and public land access which are factors that are regulated by OFWAT (the economic regulator of the water sector in England and Wales). Commercial forestry was not a priority, although they do manage woodland and generate income from extracted wood.

The local authority foresters prioritised recreation and public access to woodland. Their woodlands were managed, and because of the rise in the price paid for wood, they were able to generate income from this management. The importance of urban tree planting was stressed by some of the foresters. Urban trees are considerably more expensive to plant and maintain than rural trees and it is difficult to find suitable land with space needed for the roots of growing trees. However, the value to communities is enormous: providing cooling, improving air quality, and enhancing quality of life. Grants for planting were available from charities such as *Trees for Cities* (Trees for Cities, 2021) who fund tree planting from corporate social responsibility (CSR) funding from businesses.

The landowners had a wide range of priorities for their land and some of them may be reluctant to plant any trees. Those who are willing to plant may have very specific ideas of the type of trees they find acceptable.

6.3.1.2 The many factors which discourage tree planting

Although there are currently many compelling reasons to plant trees, and financial support and advice are available, in practice there are many reasons why landowners will not, or cannot, plant trees on their land.

Landowners are reluctant to plant on any land which is likely to gain planning permission for development because of the potentially high value of that land, particularly in peri-urban areas

(*LAF2*). Landowners can be subject to restrictions on planting in national parks, historic landscapes, SSSI, AONB, and in habitats with protected species. For example

> *'the challenge in parts of Yorkshire is wading bird populations, so up in Swaledale and some of the upland areas of Yorkshire there are nationally, arguably internationally, important wading birds: populations of curlews and lapwings…if you have got those nesting on a site or frequenting a site, it's very unlikely that you'd get permission to plant trees anywhere near it.' FTREP.*

Planting on moors and heathlands can also be prohibited:

> *'being moorland, probably the amount of woodland planting would be restricted to gill planting, in the bottom of valleys and things, so it wouldn't be on any large scale I don't think because the main interest there would be the heathland.' CLO.*

However, one interviewee had planted in the Yorkshire Dales National Park and a second planned to plant in an AONB, so it can be seen that policies vary. Both plantings were restricted to native species. An AONB advisor insisted on 100 % native species:

> *'She was quite keen for us to stick to native species. My husband was pushing for having some pine trees because it would soak up some of the moisture, but she said no.' SLO.*

Tenants are less likely than farm owners to plant trees. The landowners interviewed (historic charity, utility and estate owners) who had tenants, were open to discussing tree planting. However, tenants, despite being eligible to participate in stewardship schemes, have different priorities from farm owners, and aim to make best use of all the land that they rent. They may be less likely to create planting schemes that tie up capital for 30 plus years, less likely to take land out of agricultural production, and less likely to invest in the aesthetics of a farm:

> *'Let land is worked harder… because you are paying for every acre. Whereas if you own it and you have got a bit of rubbishy land, well bigger picture you can put some trees on it and look at the long term picture. Whereas if you are tenanted, it is year on year trying to make every penny you can off every acre you have got.' EO2.*

Tenants may also be less likely to change their farming activities, e.g. the utility landowner thought that:

> *'the people who occupy our land are agricultural, i.e. "I do sheep. I do cows, I don't do trees". That is what they are trained to do, so the incentive to plant trees*

might be so far from their comfort zone, their knowledge zone, they will continue to grow sheep and cows because that's what they know.' ULO.

One of the farmers had only been able to plant trees after buying his farm, having been a tenant farmer before that:

'It's an interest we have always had. … since… we have been owners rather than tenants that allows us to do what we want to do.' MF1,

and he now has 10 ha of woodland to encourage wildlife, and to support shooting.

6.3.1.3 Pests are a significant problem for woodland owners

Pests, the resulting costs of protecting trees, and the risk to the value of a timber crop are big problems for woodland owners. The potentially devastating effect that grey squirrels, deer, rabbits and voles can have on woodlands, especially on broadleaves, was a topic raised by most of the woodland interviewees, and for some the risk of pest damage was the main barrier to woodland planting.

Managing grey squirrel populations through shooting and trapping, and providing guards and fencing to protect newly planted trees from rabbits is costly. Allowing the grey squirrel population to rise can result in damage to trees of any age, and this can reduce their yield and change their form: making them unsuitable for timber. For example, squirrels:

'…can ruin an oak plantation inside a season. Just eat the tops out, so you have lost it. In some ways it is quite a risky investment unless you have the money to invest on looking after them.' FCF2.

Broadleaved trees were particularly vulnerable to squirrel damage:

'If you are growing ... broadleaves, then the grey squirrels will just trash your woodlands, you can get a tree that's 18, 20 years old, and the grey squirrels will debark it and it will go from something that could have produced timber to something that's firewood at best.' FTREP.

Voles were a less widespread pest but could cause considerable damage to newly planted trees:

'The vole: he's a monkey. What he likes to do is go and nest inside the tree guard, in the winter, because it's nice and warm and cosy, and it's plastic and it's like a little greenhouse. And then he…wakes up after a dormant period and starts eating the bark.' AF3.

The cost of pest control, the choice of tree species and risk of pest damage needs to be considered in any woodland planting.

6.3.1.4 Foresters think that timber production is being overlooked

Commercial foresters thought that timber production was overlooked by government policy and environmental campaigners. Foresters' main priority was timber production, but they argued that commercial forestry always brings with it a host of benefits to the environment, such as pollution reduction, flood control, carbon sequestration as well as recreational opportunities.

They thought that charities and NGOs had too much power in shaping government policy. The promotion of exclusively native broadleaved planting was restrictive, and not best for timber production, or for resilience to climate change, pests, and diseases. It was however, going to result in a lot more woodfuel at the expense of timber.

The timber markets want trees for timber but the focus of planting native species will not deliver it:

> *'What the industry wants is straight white softwood or straight white Douglas fir and larch … we have been saying this for 50 years and unfortunately a lot of the NGO pressure is to plant broadleaves. All that is resulting is us importing more and more timber. That's why timber prices at the moment in England and across the UK are very high… a lot of the broadleaves that were planted [in the] 90s was at 3 m spacing, not really looked after, so a lot of that will not really produce anything other than firewood.' FTREP.*

But the charities were promoting 100 % native planting:

> *'by planting native trees you really are limiting things quite considerably and you are more at risk from failure if there is a major disease outbreak, or pest', FCF2.*

The current Countryside Stewardship grants for plantings of over 3 ha specify a maximum of 20 % non-native and 20 % honorary native planting (Rural Payments Agency, 2018b), but the *Woodland Carbon Fund* scheme (Forestry Commission, 2019d), for productive plantings over 10 ha allows more non-native species to deliver 70 % productive woodland.

6.3.1.5 Government policy is not effective in driving tree planting

The Government is supporting tree planting through advice delivered by FC woodland officers and grants delivered by Natural England (NE) as agri-environmental schemes, but these are not delivering the significant planting of new woodland that was hoped for.

Agri-environmental stewardship schemes for agriculture and forestry (see **Box 3**) were viewed as complex and onerous by the farmers interviewed. Although the estate owners and some of the larger farms were still taking part in stewardship smaller farms were dropping out of the schemes:

> *'It's not straightforward. We have assistance putting it together and I guess we have more knowledge internally than most landowners. Speaking to some of our tenant farmers, they don't have stewardship schemes because they haven't got support to do an application. It is too complicated.' EO3.*

The general opinion was that more and more was expected for less money in return, and there was a fear that if a scheme was not successful, e.g. if trees did not all thrive, then payments would be clawed back.

Interviewees thought that Natural England didn't really understand forestry and the conditions they imposed were unrealistic. The result of this complexity is that farmers and landowners are not taking up the tree planting schemes, and so planting is not taking place. Commercial and FC foresters thought that Natural England did not have the level of expertise previously provided by the FC and as a result the grants and stewardship schemes were not fit to cope with the levels of planting proposed:

> *'the process of obtaining grants could be simplified. The landowner doesn't really have to deal with that. That is down to us to deal with and it is a pain. They are not the simplest format. Also, you have several different organisations with Natural England, the Forestry Commission, and other stakeholders such as Historic England, county archaeology, and it can take a long time, things get lost, mislaid, forgotten about. There is a lot of chasing up.' FOR1.*

To cope with the desired planting volumes would require:

> *'a sea change in how we process new planting applications because at the moment the mechanics, the mechanisms that new planting applications go through would really struggle with 10,000 ha a year. We need a new system for doing that.' FTREP.*

Some of the interviewees were interested in agroforestry and were aware of the potential benefits but they found that there was no government policy to support the practice. Agroforestry (see **Box 5**) falls between the regulations for agriculture and forestry, and not only are there no policies to encourage it, but existing policies are a barrier to its development.

Farmers were concerned about the impacts of Brexit and the new agriculture policy on their livelihoods. Several of the interviewees intended to plant more trees but most were delaying planting until they knew whether the post-Brexit public goods based farm payment (ELM) would offer better incentives:

> *'I was going to do another strip this last winter…to make it a bit of an avenue of trees, but then I heard about the Government thinking. Well our future money from the Government will be environmentally based, so it seemed crazy to be planting when potentially there could be benefits from holding back a year or two.' AF1.*

Box 5: Agroforestry

Agroforestry is the integration of trees or shrubs with either agricultural crops (silvoarable) or livestock rearing (silvopasture). Without reducing the area of land available for food production, this can deliver: ecological and economic benefits such as increased productivity, increased carbon sequestration in the soil, flood and soil erosion control, improved animal welfare, and woodfuel for bioenergy. The UK Government does not have a clear policy on agroforestry, which currently does not qualify for farm payments, environmental stewardship or forestry grants. The planting density in agroforestry is typically 75-200 trees per ha, which is too low to qualify for woodland creation grants (which require a minimum of 400 trees per ha). Permanent planting can result in the loss of BPS income (Soil Association and Woodland Trust, 2018).

There was a generally positive attitude to the potential, post-Brexit, of UK policy discouraging grant farming of upland areas (where sheep grazing is causing erosion of soil and flooding), and instead promoting tree planting that would improve the environment, reduce flooding and increase carbon sequestration.

6.3.1.6 The Northern Forest could drive significant planting

The Northern Forest (see **Box 6**) project has a target of planting five million trees in the north of England but the farmers and estate owners interviewed were not involved. The local authority foresters, utilities and charities were working with the Northern Forest but faced the challenge of finding land where the landowner was willing to plant trees. There are a lot of small community projects which will probably plant on a small scale – probably '30 to 100 trees' *WCR*. The utility company interviewee had an ambitious planting target and intended to work with tenant farmers and a charity to take land out of agriculture and plant a million trees.

The commercial and FC foresters were concerned that the full potential of the northern forest would not be achieved if charities and public bodies were going to promote 100 % native broadleaves and did not include some productive forestry and non-native species in the project. *FOR2* warned that:

> *'If you planted the Northern Forest with broadleaf you will just create a massive buffet for deer and for squirrels.'*

Box 6: The National Forest, the Northern Forest, and the Northumberland Forest

The National Forest was established in the Midlands, between Birmingham and Derby, to regenerate the landscape and environment of a formerly heavily industrial area. Since 1991 the National Forest Company has supported the creation of 7,250 ha of woodland (planting over 9 million trees) and still supplies advice on planting and management, and grants for landowners *(The National Forest, 2020).* The National Forest is expected to produce enough energy to supply electricity to 26,900 homes (Woodland trust 2018).

The Northern Forest (Woodland Trust, 2018a) is a partnership between the Woodland Trust and four community forests in the North of England, including the Leeds White Rose Forest. Their aim is to plant 60 million trees in 25 years and some government funding has been promised. As well as improving the environment and sequestering carbon, the project is expected to provide a local supply of timber and woodfuel (Woodland Trust, 2018b).

The Northumberland Forest was set up in 2019 as a public-private partnership. Forestry England (the branch of the Forestry Commission responsible for managing the publicly owned forests in England) has planted on 100 ha of land purchased for forestry: something that had not happened in the UK in the previous 20 years (Forestry England, 2020).

6.3.1.7 The division between forestry and farming is starting to breakdown

Traditionally there has been a division between forestry and Farming (see section 3.5), but this is beginning to breakdown as forestry knowledge is being picked up by farmers. This has traditionally been a cultural split: '… *farmers perceive themselves as farmers, they don't see* *themselves as foresters.' FTREP.* This division has been perpetuated by colleges and universities in the UK where a typical agriculture course:

> *'didn't have any forestry components in it. If you are doing forestry there aren't any agriculture components. So we are very polarised: two separate sectors.' WCA.*

This divide between farming and forestry may be narrowing, helped by recent improvements in the coverage of forestry in the farming-press, e.g. interviewees had seen articles in Farmers Weekly on the rise in the value of wood for fuel. Forestry companies were trying to bring in new business through social media and through rural events and shows. Annual reports on the industry are available from Confor and from commercial forestry companies. The FC, WT and forestry industry bodies are all trying to make farmers more aware of the benefits of woodland, and the Government plan for delivering forestry grants through stewardship schemes was intended to breakdown the division.

6.3.1.8 Woodland management levels are increasing

Attitudes to woodland management vary depending on the type of landowner, but the level of management is increasing as a result of the rising price of woodfuel. The estate owners interviewed used commercial forestry companies to managing their woods to FSC (Forest Stewardship Council) standard (FSC UK, 2021), but they knew of other estates that still have their own foresters. The estate owners had woodland management plans in place which had a wide range of commercial, environmental, and aesthetic targets including: developing biodiversity, maintaining capital value, maintaining and improving the aesthetics of the landscape, sustainably managing the forests over the long term, maintaining pubic rights of way, increasing stand diversity, and maintaining sporting benefits. The estate owners with listed or historic landscapes prioritised the quality of the landscape: restoring original planting plans, managing historic woodland, or restoring PAWS (plantations on ancient woodland sites). The utility company, historic charity and local authorities were all managing their woods and generating income from extracted wood.

The level of management is not as high on farms as on estates, and one FC forester based in Yorkshire thought that:

> *'the majority of woodlands in my area are managed, … maybe because they are large estates and they are professionally looked after anyway. So we don't have a lot of small woodlands, say farm woodlands and things like that. They are the ones that tend not to be particularly well managed.' FCF2.*

Another FC Forester, *FCF1*, thought that failing to manage farm woods was generally caused by *'apathy or through misconception'*: the misconception being that doing nothing is the best thing for the environment. Some farmers were not aware that they needed to manage the woodland they had planted, and others had woodlands that had always been a part of the farms that had never been managed. However, to make these neglected woods productive may require:

> *'a change of mindset really, because we are used to, in our part of the world anyway, to having woodland as wild areas that just go their own way, some of them may be valuable habitats for wildlife but they are certainly not very productive.' AF6.*

Farmers are becoming aware of the increase in the price of wood and the potential for income from management. Now it can be economic to bring in foresters to thin even small woods:

> *'Some of the smaller scale, small operations: thinnings, small shelter belt woodlands that sort of style of woodland, were probably considered unviable only a couple of years ago because they just wouldn't cover their operational costs. We couldn't offer anything back to the landowner. But now … it has been encouraging, certainly smaller landowners, to bring those unmanaged woodlands back into management.' FOR2.*

Farmers with more established woodland were managing their land to produce woodfuel which they either sold or used on the farm. Though most farmers were aware of the recent increase in the price of woodfuel, others were not and they still viewed management as a cost not a potential income stream:

> *'It's one of the challenges you'll get, a farmer might have sold timber five years ago and got nothing for it, and having his fields trashed at the same time trying to access the timber. So in the farmer's head it will be perceived that the timber is worth nothing, whereas now timber has more than doubled in value.' FTREP.*

Although levels of management are definitely increasing, one forester warned that the FC figures on woodland management may be overstating the level of management actually carried out:

> *'58 or 59 %... all that figure is, is an indicator of the proportion of woodland that has had a felling licence approved in the last 15 years or has had a grant of any sort in the last 15 years.' FCF1.*

In practice the licenced areas may not all be actively managed. For example, one farmer's ten year management plan shows how easily the management level could be overstated. To get his felling licences agreed he had to:

> *'specify areas that in the next ten years you think that you are going to need to sort out … it saves you applying for felling licences for every bit as you go through and it is not compulsory. You don't have to do it if you don't want when the time comes. But it is just one of those that gives you the option.' MF1.*

Poor access remained a barrier to woodland management, especially on steep upland sites. No grants were available for putting in tracks to aid harvesting of existing woodlands and so it was felt that some of the woodland area in the region would never be harvested.

6.3.1.9 RHI has created a market for woodfuel and encouraged woodland management

The RHI has supported the growth of a market for woodfuel in the UK by encouraging the use of sustainably sourced woodfuel, and the installation of wood burning boilers and stoves. Foresters were aware of the impact of the RHI on the prices achievable for woodfuel, and found that this had transformed attitudes to woodland management, by encouraging thinning and felling to produce woodfuel for sale. It has also encouraged woodland owners to install their own boilers and manage their own woodland to become self-sufficient in fuel.

The foresters interviewed saw a clear link between the RHI subsidies e.g.

> *'A lot of new enquiries, it's neglected broadleaved woodlands. So, I am taking out the worst trees and leaving the best trees, and that is all going into the firewood market. Yes, that has been driven by RHI.' FOR1.*

The levels of management have increased as a direct result:

> *'Because of where the market is now, with the price pushed up by the RHI, or biomass bubble, or whatever we want to term it, I don't think there is any excuse for woodland not being in management in England, unless it is horrible to access.' FCF1.*

One forester observed that the RHI had been too generous. As well as increasing the price of woodfuel, the RHI has increased the price of wood used for other purposes, such as chipboard, because of:

> *'the subsidised RHI payment to the biomass industry. It has distorted the market. So the timber supply market, the price of timber has gone up dramatically because of that distortion. An over-subsidy I would say that maybe has gone to biomass.' FCF2.*

6.3.1.10 Regional factors

The tree cover in Y&H, at only 6 %, is low even by UK standards and, combined with the opportunities provided by the Northern Forest, there should be scope for significant planting in the region. Y&H is on the southern edge of the area of the UK where commercial forestry is widely practised so there are commercial forests in the region which can be observed by prospective landowners, and there are relevant skills in the region. There has been little large scale new planting in England and Wales in recent years – and a planting of over 100 ha is very rare (*FTREP*). Although landowners in Y&H may be more open to planting than those further south, conditions are very different from Scotland where forestry is being strongly supported as an industry. There are lots of protected landscapes in Y&H: the Yorkshire Dales and Yorkshire Moors national parks, AONBs, listed landscapes and protected upland habitats. National parks may promote planting e.g. the Yorkshire Dales Millennium Trust promote planting, but other areas may not allow it, or may apply restrictions to the planting allowed. Some of these restrictions will be faced in other areas of the UK.

6.3.1.11 Prospects for woodland creation and management

Confidence in forestry was generally high among the interviewees because of the strong prices paid for timber and woodfuel, and the feeling that the role that tree planting can play in mitigating climate change, flooding, and air pollution was being recognised by the Government, the media, and the public.

There was concern among farmers about the impact of Brexit and the new agriculture policy on their livelihoods. However, the weak pound was making UK timber competitive and boosting the forestry sector. Several of the interviewees intended to plant more trees but were waiting for the new ELM scheme (see **Box 3**). There was a generally positive attitude to the potential, post-Brexit, of UK policy discouraging grant farming of upland areas, and instead promoting tree planting.

6.3.2 Drivers and barriers for woodland planting and management

The drivers and barriers identified from thematic analysis of interview data and discussed in the sections above, are summarised below in **Table 6.4** for woodland planting, and in **Table 6.5** for woodland management.

Table 6.4 Woodland planting drivers and barriers

Drivers
Grants are available for planting, fencing and guards
Provides a long-term investment which can be cashed in when needed
Diversification of farm activities – risk spreading
Shelter belts and farm warming
Provides a supply of woodfuel for farm/estate
Creates habitats for greater biodiversity
Creates attractive landscapes
Controls flooding and improves water quality
Inheritance tax advantages
Provides shooting cover
Recreation for landowner and the public
Low maintenance use of poor-quality land, or awkward corners of farms or estates
Climate change mitigation
Replacing trees lost to storms or disease
Northern Forest is encouraging planting
Charities fund planting and restoration in rural and urban areas
Tree planting is attractive to companies looking for CSR activities and carbon credits
Local authorities have commitments to provide tree cover
Planting needed for certification of farm products
Barriers
Initial planting costs of trees, guards, and fencing
Loss of income from agriculture and long wait for income from wood
Loss of farm payment unless planted in a stewardship scheme
Competing with grant farming on upland farms
Woodland grants may be too restrictive on species and layout
Permanent land use change is not attractive to farmers
Fear of reduction in value of land when it is changed from agricultural to woodland
Complex grants can scare off farmers who fear grant payments may be clawed back
Hope of building on land
Division between farming and forestry industries
Reluctance to plant over the ‘sweet spot’ for tree planting of about 7 % for a farm, and not more than 25 to 29 % for an estate

Table 6.5 Woodland management drivers and barriers

Drivers
Higher price of woodfuel means it is now profitable to carry out thinning
Coppicing creates employment and woodfuel
Thinning provides woodfuel for a farm or estate
Woodland management grants are available
Can increase value of woodland
Creates an attractive landscape
Barriers
Difficult or no access to extract wood from remote or steep sites
Lack of knowledge of need for management or apathy
Attitude that neglect is best for woodlands
Lack of awareness of increased price of woodfuel
Lack of forestry skills

6.3.3 Discussion of woodland results and conclusions

The woodland interviews were carried out to identify the barriers to woodland creation which have resulted in the UK failing to hit woodland creation targets, and the barriers to woodland management that have led to under-management of UK woodlands. The barriers have been identified above, and now the DOI innovation-decision process (Rogers, 2003, p170) is used to structure a discussion of the factors influencing the landowners and farmers when they consider planting trees and how some of the barriers to cultivation could be overcome. This is followed by a discussion of woodland management barriers and finally conclusions are drawn from all the woodland interview data.

6.3.3.1 Why has woodland planting failed to meet targets?

For the UK to meet planting targets, landowners must be willing to plant trees on their Land. The decision-making process for landowners who are considering woodland planting is analysed below using the DOI framework.

Prior Conditions

For most farmers their previous practice was arable or livestock farming, and this was the norm for their social system. Estates had a history of commercial forestry, and also farming by the estate management and/or tenant farmers. Forestry was a core business for estate owners and had been for generations. The norm for charities was to preserve or restore the historic landscapes or protected habitats, and utilities considered woodlands as a way to improve flood control and water quality, which also delivered income and recreational opportunities.

A desire for a nicer farm environment often motivated farmers to plant trees: adding recreational areas, replacing lost trees, or providing wildlife habitat. The need for shelter or a use for an awkward to cultivate area can also prompt planting. Landowners were well aware of the many environmental benefits of planting trees, and the desire to improve the environment underpinned many decisions. For estate owners, new planting of trees was often initiated by restoration of landscapes or as a part of a long-term land management plan.

Innovative landowners had already explored business diversification, new practices, and potential sources of grants, and were open to new business and environmentally beneficial ideas.

Communication Channels

Most farmers and landowners had well-developed networks of fellow farmers, land agents, foresters, friends, and relatives, and were well informed through their networks and through the farming press. They were members of either the NFU and/or the CLA, and both organisations were spreading information about forestry.

Step I: Knowledge

The farmers interviewed all owned all, or part, of their farms, either individually or in family partnerships. Some had bought their farms, but most had inherited them. They were prepared to forgo short-term income, and risk a possible reduction in land value, when planting small areas of woodland that would benefit the local environment and mitigate against global climate change. Estate owners had inherited their estates which had been in their families for hundreds of years, and managed some of the land directly as well as having tenants. The environment and the future of the farm and landscape were important to farmers and estate owners who were all planning for future generations. Charities were concerned about the views of their members (who fund the charity), and utilities have to satisfy their regulators on key measures.

Step II: Persuasion

For small plantings the perceived advantage was environmental and aesthetic, and the grants available partly compensated for lack of income and land-value reduction. For larger plantings the grants were more important and the activity needed to be more financially attractive, providing a long term savings scheme e.g. to pay out on retirement, or as a farm diversification.

Tree planting was viewed by the farmers interviewed as being compatible with farm activities: fitting in around farm work and enhancing the appearance of the land. However, it was not always considered to be compatible with the *image* that farmers had of themselves as food producers. Although the complication of planting on tenanted land has been recognised, (Lawrence and Dandy, 2014; Eves et al., 2014b) and it was understood by the interviewees that tenants were less likely to plant trees on their land, all the landlords interviewed (utility, charity, and estate owners) were willing to work with tenants to plant trees on their land.

Within the group of farmers interviewed, the attitudes to planting were relatively consistent. The sample group was too small to segment in the way that Eves et al. (2014b) had done; although the attitudes of the interviewees were similar to those of the '*pragmatic planters'*, '*willing woodland owners'* and '*casual farmer'* segments who all had an interest in conservation and habitat and were the farmers most likely to plant woodlands. Growers of energy crops had previously been found to be more likely to plant trees than the average farmers (Hopkins et al., 2017) and although the sample of farmers interviewed here was small, it is interesting to note that four of the seven energy crop growers had planted trees on their farms.

Tree planting was not viewed as complex but management was, and some farmers needed advice or help with management. Estate owners (including utilities) who employed foresters or forestry companies for woodland planting and management were not concerned about complexity.

Small plantings could be trialled subject to minimum planting areas, but all plantings were viewed as permanent. There were plenty of opportunities to observe planting schemes locally.

Steps III, IV and V: Decision, implementation, and confirmation

Many of the farmers had planted trees on a small scale but were less comfortable with planting larger areas and many continue to reject larger scale woodland planting. The smaller plantings did not always need to be economically viable: the farm owners have the agency to make these decisions over land use which will benefit future generations. The farmers who had planted trees were happy with their decision and some have made a series of additional plantings of 1 to 5 ha, confirming their decision. This willingness to plant again is consistent with the findings of Eves et al. (2014a) (that farmers with existing woodland are the most likely to plant trees) but for farmers these plantings are likely to be small, and larger plantings were rare. Most of the farmers interviewed did not consider tree planting as a core farming activity: it was either a diversification, or in some cases a luxury.

Although estates are confident managing large areas of forestry, they must balance forestry with farming and other income sources, and will only want to devote a certain proportion of their land to forestry. Estate owners were only willing to adopt tree planting up to the 25 to 29 % range, significantly above the 7 % that farmers are comfortable with for a farm, but those with lower percentages of woodland could be encouraged by grants to make significant plantings. Landowners who have protected or historic landscapes may be unwilling to increase their percentage of woodland.

At the time of the interviews, the charity landowner was found not to be interested in increased woodland cover as they prioritised the preservation of landscapes or habitats and had no interest in forestry as a business. However, since the interviews were carried out the National Trust has pledged to plant 20 million trees by 2030 (National Trust, 2020) as the level of public interest in trees has risen (Tilhill Forestry and John Clegg & Co, 2019) see **Box 7** below. Utility landowners have land that could be planted but water quality not forestry income is their priority. Although these landowners will not be motivated solely by grants; public opinion and pressure from supporters or shareholders could be effective at encouraging woodland creation.

Local authorities were very enthusiastic about urban planting which, although it is valuable to residents, and may be a priority for the Northern Forest project, is unlikely to make a significant contribution to UK planting targets. There seems to be more scope for the Northern Forest to work with farmers and private landowners who are currently not involved in the project.

Some landowners rejected tree planting in the short term, hoping that the incentives to plant would be higher post-Brexit under the new ELM scheme. Later adoption remains an option but discontinuance by clear felling is very rarely an option.

Box 7: Media attention on tree planting.

Tree planting became a very high-profile topic in the media in 2019 and 2020, particularly during the campaign leading up to the general election on 12 December 2019, when tree planting became a political issue. Although the campaign was dominated by Brexit and NHS funding, with very little attention paid to climate change, tree planting became headline news as the parties competed to set successively higher tree planting targets. The Conservative Party pledged 30 million trees per year, the Liberal Democrats 60 million per year, the Green Party 70 million per year and finally the Labour Partly pledged 100 million per year, or 2 billion by 2040 (Morris, 2019). These targets were stated as tree numbers with no indication of areas to be planted or how the land for planting was to be found.

In January 2020 the National Trust announced that it would be planting 20 million trees on 18,000 hectares of land to increase the proportion of woodland on their land from 10 % to 17 % which would bring it into line with the CCC (2019) *Further Ambition* target for the UK.

The CCC land use proposals for meeting the net zero target (CCC, 2020a) received much media attention – much of it focussed on cutting meat consumption and taxing air travel to pay for tree planting (Vaughan, 2020).

6.3.3.1.1 DOI categorisation of landowners

Farmers and landowners can be assigned to one of Rogers' adopter categories according to their attitudes to creating woodland as a business activity. Small scale plantings have been carried out on farms for many years: this is not new. However, taking the next step to larger scale planting and considering woodland as a core business rather than a luxury, is for farmers, an innovation that is still at an early phase of adoption. Both *AF5* and *AF6* had come to view woodlands as a part of the business and *MF1,* with a ten year planting plan, also viewed woodland as a commercial activity: they could all be categorised as early adopters of larger-scale woodland planting. The other farmers who planted on a smaller scale may in future invest in woodland as a business activity, but will fit into one of the later adopter groups.

Large scale planting for estate owners is not an innovation: it has been a core part of estate management for generations. However, significant planting, taking the proportion of land forested above the current norm, could be considered as innovative, particularly anywhere south of North Yorkshire

Significant woodland planting could be an innovation for charity landowners and utilities too. While increasing woodland area had not been a core activity in the past, they are particularly susceptible to pressure from members, supporters or shareholders demanding action on tree planting which could lead to significant planting targets.

6.3.3.2 Woodland creation discussion and conclusions

There are lots of compelling reasons to plant trees, and tree planting is receiving positive government and media attention. There is a wide range of grants for planning, planting and for annual maintenance of new woodlands, available from the UK Government and from environmental charities. Most of the interviewees who took part in this research were enthusiastic about planting trees and it might be expected that significant tree planting would be underway in the UK, but the enthusiasm and support for trees has not been converted into major new planting. There is still a wide range of barriers, discussed above and listed in **Table 6.4**, which are discouraging landowners from planting trees on their land.

The financial barriers identified in previous studies, of the initial cost of planting, the loss of income from the land for at least 15 years, the loss of farm payments, the permanent loss of farmland, and the risk of reduced land values (Hardaker, 2018; Forestry Commission, 2017a; Forestry Commission, c2006), were all still acting as barriers to planting. The cost of protecting trees from pests and the long-term risk of pest damage to the value of the crop was a particular concern for the interviewees. Although grants are available for planting and maintenance, these are failing to fully compensate for the financial risks of planting and loss of annual income, are viewed as complex and not fit for purpose, and landowners carry the risk of having to repay grants if establishment fails.

To get more significant planting, above the 7 % '*sweet spot'* for a farm, then a different attitude is needed from farmers: cultural, as well as financial, barriers will have to be overcome. The cultural division between farming and forestry, and in particular the entrenched attitude of farmers who feel that they should produce food not trees (Lawrence and Dandy, 2014; Hopkins et al., 2017; Hardaker, 2018) were familiar to some interviewees. The failure of agricultural education to overcome this division was also identified, and continued education of farmers is needed from the FC, Natural England, and the forestry industry.

The reluctance to plant on peri-urban land, because of the hope of securing planning permission for building, is preventing planting in areas where it would have most public benefit. There could be opposition to planting on land in national parks, AONBs or SSSIs, protected heath and moorland, and areas with protected birds. If significant planting is to be achieved in the UK then the restriction on trees in some of these areas may need to be reviewed. Similarly, the pressure from charities and NGOs to plant 100 % native species may need to be resisted, so that more conifers can be planted to aid establishment, provide resilience to climate change and pest damage, and to maximise carbon sequestration.

The Northern Forest project was found to be working mainly with community groups, charities and local authorities and had not engaged private landowners. It could increase its impact by broadening its engagement to include farmers and landowners. The foresters interviewed felt strongly that the Northern Forest should include a proportion of productive, non-native species.

There was considerable interest in agroforestry which could improve canopy cover and carbon sequestration without reducing food production. Government policy should be revised to remove the penalties incurred (loss of farm payments and ineligibility for woodland grants) and to encourage the delivery of public goods.

Many landowners were delaying planting until the new ELM scheme is in place in the expectation that future grants, and the payment for delivering public goods would be more attractive than current incentives. However, ELM will not be fully implemented until 2027 and this could delay planting, despite reassurances from the Government that planting before ELM will not put them at a disadvantage (Forestry Commission, 2019c).

Upland farms are often viewed as most suitable for tree planting. They may have poor quality pasture grazed by sheep and need farm subsidies to be viable. These farmers could be persuaded by suitable grants to plant trees on their land. However, upland planting may not deliver the same benefits (to the farmer or to the environment) that lowland planting provides, especially if planting is limited to native broadleaved species that can fail to thrive in exposed positions. The volume of wood produced and the CO_2 sequestered could be disappointing.

The attitudes to planting trees and the barriers preventing planting were found to be different for different types of landowner and different action will be needed to prompt them to plant trees on their land. Farmers and estate owners are obvious candidates for planting but the land held by other institutions should not be overlooked: charities, the Crown Estate, MOD, local authorities, and other public bodies should all play their part.

In conclusion many barriers remain to woodland creation in the UK. The financial incentives on offer are not providing the level of support needed to make the risk of permanently changing land use acceptable to farmers and landowners, and the grant system is too complex for farmers to negotiate. Much is expected of the new ELM scheme, but few details were available at the time of the interviews. Since then, more information has been announced: see **Box 8**. As well as financial barriers many cultural and attitudinal barriers remain, and these will have to be overcome before farmers adopt forestry as a core business activity.

The barriers identified here, and the suggested government actions required to overcome these barriers, were used as input to the policy analysis in the next phase of research, the results of which are reported in the next chapter.

6.3.3.3 Woodland management discussion and conclusions

In the past the main reasons for failing to manage woodland included: failing to realise that it was needed, apathy, the cost of management and a lack of skills (Eves et al., 2013). Although the level of woodland management was reported as 58 % in the UK (House of Commons, 2017) this could be over stating the position. Management is higher in conifers (100 %) than in broadleaved woodland (20 %)(CEH and Rothamsted Research, 2019). The prospects for increasing the management of broadleaved woodland are good. The introduction of the RHI has helped to establish the UK supply chain for woodfuel, and the recent increase in prices has made woodland management a profitable practice even for owners of small woodlands who can employ contractors, thus avoiding the need for specialist skills. Knowledge of the profitability of management is spreading via the farming press, from forestry companies' marketing activities, and word of mouth. Support from *Woodland Management Plan Grants* (Rural Payments Agency, 2019) should also lead to higher levels of management.

Although this research suggests that management levels have increased, the level of management reported by the FC (Forestry Commission, 2020a) has remained at 58 or 59 % from 2015 to 2020 with no apparent increase in management levels. It is possible that more management plans have become active over this period although the total area covered by plans has not increased. Poor access and difficult ground are likely to remain as barriers, and the deliberate neglect of woodland, based on the view that neglect is the best thing for wildlife (Dandy, 2016), is likely to persist among some landowners.

Although the Non-domestic RHI will close to new entrants in 2021, and the domestic RHI scheme in 2022 (BEIS, 2020e), payments will continue to the end of the 20 year terms so the market should continue to thrive for some time, even if any new schemes do not support woodfuel. As the level of management of UK woodland seems to be increasing as a result of the success of the RHI, and farmers are becoming aware of the need to manage woods and its benefits, no research will be carried out into overcoming the remaining barriers to woodland management.

6.4 Common themes from stakeholder interviews

This section contains an overview of the findings from all three types of stakeholder interview, highlighting some of the common themes and trends that were identified.

Comparing the impact of the RHI scheme across the three types of biomass reveals some contrasting findings. It has been effective in creating demand for litter and energy crops to be used in AD, and for increasing the management of woodland to produce woodfuel. However, it has not been effective in promoting small scale PEC heat projects, possibly because of the more complex boiler requirements, and has little impact on small scale poultry litter combustion because the incentive is also offered to woodfuel and heat pumps. The success of the RHI for some technologies is encouraging and lessons should be learned from this when designing any successors to the RHI, and formulating the new UK Biomass strategy.

Whenever energy crops were planted, they had to be financially viable for farmers, whereas for small plantings of trees farmers *did not* require a direct financial benefit from their trees which they often considered as an aesthetic enhancement of the farm or a luxury. However, for larger plantings, forestry was considered a business and had to deliver a profit. This is another indication that farmers do not currently consider forestry as a business.

Some interesting trends were observed from comparing the decision-making processes for the adoption of energy crops and woodland creation. These are discussed in the following section.

6.4.1 Trends in adoption

When the results of the DOI analyses for maize, grass, miscanthus, willow, and woodland creation were combined, some trends were observed which can explain the current activity and could be useful in predicting future behaviour. **Table 6.6** contains summaries of the five DOI decision-making factors of relative advantage, compatibility, complexity, trialability, and observability for each crop, together with an indication of the *general perception* of the crop, based on the interview data.

Trialability in the DOI model is a measure of how easy a practice is to adopt on a small scale or without committing a large financial investment e.g. by borrowing or leasing technology (Rogers, 2003). However, the important factor to the interviewees was not just the *scale* of the commitment, but the *term* of the commitment, so *term* was also included in **Table 6.6**.

White et al. (2009) suggest that risk should be added as a sixth factor to Rogers' five perceived characteristics of an innovation. Risk was also identified by RFS (2020) and Galik (2015) as a key determinant of propensity to plant. An economic definition of *risk* (Sloman and Garratt, 2013) is the uncertainty of an outcome where the probability is known. *Uncertainty* is 'the chance occurrence of some event where the probability distribution is genuinely not known', and this uncertainty can lead to positive or negative effects (Smith et al., 2014, p. 3). Often, the probability of a risk to a project or business activity is unknown and it is really the uncertainty that is considered. The meaning of risk will be taken to be “the effect of uncertainty on objectives” (Infrastructure Risk Group, 2013, p. 48). The risks to a farmer growing a novel crop (including trees) could include: weather, crop yield, fluctuations in crop price, land values, interest rates, subsidy levels and regulations. Risk was included in **Table 6.6** and a very simple risk rating given to each crop. This shows a steady increase from low-risk annual energy crops through miscanthus then willow to woodland creation as the highest risk. It could be argued that risk rather than being a sixth factor is actually determined by some of the other factors such as the complexity or trialability of the crop, and length of commitment which are clearly key factors in the risk to the farmer.

Some interesting trends can be observed in **Table 6.6**. Annual contracts for maize and grass, were widely available, the crops were compatible with traditional farming activities and attitudes, were not complex, were easy to trial and observe, and were perceived overall as a new crop which was easy to adopt. They required the shortest term of commitment and carried the lowest risk for the farmers. It is not surprising that these crops have been popular with farmers.

Miscanthus was viewed as being similar to traditional crops in many ways, but required a fifteen-to-twenty-year commitment, and carried a higher risk. Willow, with a longer commitment, higher risk and viewed as being more like trees than arable crops, was a bigger step for farmers to take, and even without considering availability of contracts, it is easy to see why adoption of PECs has been so much lower than AD crops.

Table 6.6 Comparison of crop attributes

Characteristic	Maize for AD	Grass Leys for AD	Miscanthus	Willow	Woodland planting
Relative advantage	Contracts available directly with AD plants. No grants available.	Contracts available directly with AD plants. No grants available.	Long term fixed price contracts available in some areas. Low input crop. Can revert to arable at the end of a contract. No grants available.	Contracts available in some areas. Long term fixed price contracts. Low input crop. Can revert to arable but may be hard to remove. No grants available.	Grants available for planning, planting, and maintenance. CAP farm payments lost. Long term investment. Long wait for income. Enhances farm environment. Income can be taken when needed. Risk of reducing land value.
Compatibility	Compatible with arable rotation and good for black-grass eradication.	Compatible with farm practices and good for black-grass eradication.	Fits well with arable farming for some farmers. Not a food crop so incompatible with normal behaviour.	Fits well with arable farming for some farmers. Not a food crop so incompatible with normal behaviour.	Work can be done in winter when farms are not busy. Very different to arable or livestock farming. Not a food crop so incompatible with normal behaviour.
Complexity	New crop but not complex.	Traditional land use – not complex.	A new crop but low input.	A new crop but low input.	A new set of knowledge and skills required.
Trialability	Can try a small contract.	Easy to try a small contract.	Can plant a few ha at a time.	Can plant a few ha at a time.	Can plant a few ha at a time.
Observability	Easily observable.	Easily observable.	Easily observable.	Easily observable.	Easily observable.
General perception	**Just a new crop.**	**Traditional land use easy to adopt.**	**Not a traditional crop or traditional land use, but *'basically a tall grass'*.**	**A *'new mindset'* needed, more like a tree than an arable crop. Fear of damage to field drains.**	**A completely separate practice from agriculture. Grants are complex and onerous. May reduce value of land.**
Term	**1 year**	**Up to 5 years**	**10–25 years**	**22–30 years**	**Permanent in most cases.**
Risk	**Lowest risk**	**Lowest risk**	**higher risk**	**higher risk**	**highest risk**

Finally, woodland creation was at the extreme end of all the trends. It had the longest commitment, is currently incompatible with current behaviour and attitudes, has the highest risk and requires the greatest change from farmers to a completely different way of life. Planting woodland is the hardest change to make, for farmers in particular, because of the shift of role from farmer to forester as well as a permanent change of land use for a potentially lucrative, but variable priced, crop of trees.

These factors of relative advantage (determined largely by the contract), length of commitment, and deviation from normal practice can explain the relative popularity of the different crops and should be factors that are considered in the design of grants or incentives.

Other changes of land use could be analysed in a similar way and added to **Table 6.6**. Energy forestry (or SRF) is likely to be very similar to traditional forestry but, with a shorter wait for income, could have a slightly lower risk. Peatland restoration or rewilding could take up a similar position on the spectrum to woodland creation if land use changes were permanent, and long-term subsidies could not be guaranteed for a land use change which is far removed from farmers' current practices.

The factors in this table and the resulting ease of adopting a new type of land use should be considered when designing policies to encourage any type of land use change.

6.5 Conclusions from stakeholder interviews

The stakeholder interviews gathered data that was used to answer research question two,

> 'What are the barriers to, and drivers for, the greater production and use of biomass for energy production?'

There are many barriers in place, and considerable government intervention will be needed to overcome them. By studying adoption of energy crops and woodland creation in the same research it became apparent that the main problem is land, and persuading the owners of suitable land to abandon their current agricultural practices and adopt new types of land use. As Rosillo-Calle (2007, p4) argues:

> *'the optimum sustainable production and use of biomass is, ultimately really a problem of land management'.*

The planting of PECS and trees are both influenced by financial and social factors and in some cases they will be competing for adoption: if not directly for the same area of land, for the investment of a farmer or landowner, and for government subsidies. The permanence of tree planting and the high risk to farm incomes from permanent land use change may mean that landowners will not plant trees. As Jonathon Scurlock of the NFU argues:

> *'they are far more likely to embrace climate beneficial measures, such as growing energy crops, or even planting isolated stands of trees, as long as there is the future possibility the land could be returned to other uses' (Gabbatiss, 2020b).*

Any policies implemented to overcome barriers to woodland creation and PECS must be aware of this competition for land.

The following chapter reports the results of research to identify and assess the policies that could overcome the many barriers to PEC cultivation, and woodland creation to deliver balanced changes to land use in the UK.

6.5.1 Reflection on reliability of stakeholder interview methods

It was felt that the 36 semi-structured interviews and attendance at a farm walk had provided sufficient range and depth of data to reach saturation as later interviews introduced no new themes. Further Interesting data could have been gained by extending the scope of interviews to cover litter merchants, more woodfuel suppliers, boiler suppliers and small-scale users of energy crops, to understand the supply chain better. However, it was decided to keep the focus of research on landowners, farmers, and their advisors.

The ease of recruitment varied by interview type, e.g. it was easy to find former growers of energy crops but harder to find current growers. It was also difficult to recruit commercial foresters and estate owners and snowballing was required to recruit enough. Finding farmers who were combusting poultry litter on their farms was hard because of the low number with compliant technology, and although neither interviewee was from Y&H, they both had knowledge of poultry farming throughout the UK.

The interviewees were selected using purposive sampling: because of their personal experience and their wider knowledge of their industry. They were not expected to be representative of all farmers in the region, but they were aware of the practices and attitudes within their sectors, drawing on their social networks for this information. There may have been too high a proportion of farmers from North Yorkshire, and particularly those with larger family-owned farms, because of the researcher's knowledge of the area and her personal contacts. It could have been useful to interview more upland livestock farmers; however, one of the estate owners and the utility landowner did discuss the problems facing hill farmers.

Inevitably, there is a risk that enthusiastic and innovative interviewees were over-represented in the research sample because of their experience of novel crops and practices, and their willingness to spare their time to share their knowledge with a researcher. Many of the interviewees belong to the group categorised by Dyer (2007) as *older innovative farmers*: early adopters who are passionate about their subject. This potential bias was considered during data analysis to minimise its effect.

Although particularly rich data were gathered from the face to face interviews (one of which included a woodland site visit) this could have been because of the particular enthusiasm and commitment of the participants who suggested a face to face interview, rather than any shortcomings of the method of telephone interviewing, and the researcher found no problem in establishing a rapport with the telephone interviewees.

There is a danger that the interviewees' preoccupation with Brexit and ELM may have obscured other relevant themes; when landowners blamed uncertainty over future payments for delaying planting trees, they may have failed to raise other concerns which will also prevent planting under normal circumstances.

Rogers' Theory of DOI was used with the findings from the literature review to construct the conceptual framework for the stakeholder interview data. This framework was used to write the interview script and formed the initial structure of codebook in NVivo (see Appendix G). The DOI theory ensured that the interviews focussed on the key steps in the innovation decision process, exploring the factors that influenced the interviewees, the communication channels that informed their decisions, the social systems within which the interviewees were operating, and the way in which attitudes to the innovations developed over time. The DOI-based script stepped logically through the experience of the interviewees, and by following these steps interviewees often provided the relevant information before the questions were asked, helping the interviews to feel relaxed and informal while eliciting a great deal of pertinent information.

DOI highlighted the importance and power of the interviewees' networks within their social systems. The interviewees all discussed their wide-ranging networks which included fellow farmers and landowners, land managers, advisors, salesmen and environmental groups which they used to exchange information

The DOI can be used to analyse the propensity of individuals to adopt innovations and assign them to adopter categories (Rogers, 2003, p267). Some of the interviewees clearly fitted into adopter categories; however, as they were chosen for their knowledge and experience, rather than as being representative of all farmers, it was felt that no meaningful conclusions could be drawn about the industry as whole from assigning adopter categories to interviewees. The decisions on farms and estates are often made by a number of partners who are members of multiple generations within a family and in these cases, it would be more difficult to assign an adopter category to a group of decision makers.

Rogers' DOI theory was well suited to analysing the decision making on litter use, energy crops and forestry. The experiences of the interviewees and their behaviour fitted well into the DOI framework and it provided clear insight into the decision-making processes and attitudes of interviewees. The thematic analysis performed on the interview data was extremely time consuming and after the researcher had already carried out the interviews and transcribed them it was considered that little more was revealed from coding and analysing the themes in NVivo, although it was a valuable tool for identifying relevant quotations and comments when required. Three types of biomass were covered in the interviews, and as a result the numbers of codebook nodes and themes were high (see Appendix G), so it was difficult to understand which factors were the most important from thematic analysis alone. By carrying out a second analysis using the core of the DOI framework (the decision-making factors) for all the different energy crops and for woodland creation (see **Table 6.6**) the spectrum of land use types could be defined, providing deeper insight into the key factors determining land-use-change decisions.

DOI has been used less often to study failures to adopt an innovation than for successful adoptions, (Karch et al., 2016) but in this study of *partial* adoption it enabled the identification of key adoption barriers as well as key drivers of adoption. Although DOI has been criticised for pro-innovation bias (Sveiby et al., 2009), the researcher did not feel that this bias was evident this research, which included examples of adoption, discontinuance and rejection (Rogers, 2003).

Although transcription was a valuable way of becoming immersed in the data, it took a considerable time and automated voice recognition transcription may have been worth further investigation, although the technical forestry and farming terminology could have caused problems.

Chapter 7 Policy analysis results

The barriers preventing cultivation of PECs, and those preventing woodland creation were identified and discussed in the previous chapter, where it was concluded that land use policies are key to overcoming these barriers. This chapter contains the results from two rounds of policy Delphi carried out to assess the policies that could overcome these barriers in the UK to answer the third research question '*What policies would be effective in increasing the production and use of biomass for bioenergy to help meet the UK's net-zero target?'.* The policy Delphi method used is described in sections 4.4.4 and 4.4.5.

First the inputs to the Delphi are described. Three land-use change scenarios for the UK, and four different strategies for allocating new land uses, were used to generate twelve different examples of the areas of woodland and PEC planting that that could be needed in England and the Y&H region. 43 policies which could help deliver this level of change were identified from literature, and from the stakeholder interview data, and then assessed in a policy Delphi. The results are presented showing the ratings that the panellists gave to the policies for their desirability, feasibility, and potential effectiveness. The reasons that were given for these ratings, and the potential problems associated with each policy are then discussed.

7.1 Land use scenarios and planting strategies

Before running the policy Delphi process, ranges of regional and national planting targets were generated to put the scale of the challenge into perspective. These targets were derived from UK level targets using two strategies for apportioning planting.

Many of the scenarios proposed for reducing UK GHG emissions discussed in the literature review (section 3.7.1). Three which had been recently produced, and focus specifically on reaching net zero by 2050, were selected for use in the regional land use model. These were the CCC *Further Ambition* and *Speculative* scenarios (CCC, 2020a) and the ESC *Clockwork* scenario (Energy Systems Catapult, 2020). The key details of these can be found in **Table 7.1**.

Table 7.1 Land use changes in UK by 2050 from three net zero scenarios

Scenario	New trees planted by 2050 (ha)	Energy crops planted by 2050 (ha)	Agroforestry
CCC Further Ambition	900,000	700,000	10 % of arable and 10 % of temporary and permanent pasture
CCC Speculative	1,500,000	1,200,000	10 % of arable and 10 % of temporary and permanent pasture
ESC Clockwork	900,000	1,400,000	None specified

Two initial land allocation strategies were defined (see section 4.4.1): *Strategy 1* with a focus on using the lowest grade land (mainly rough grazing and temporary pasture) for planting PECs and woodland, and *Strategy 2* using slightly higher grade land (MAFF, 1988). Both were informed by discussions during the stakeholder interviews (see chapter 6) and literature (see section 3.7.1), and were intended to provoke comments from panel members. The strategies are defined in **Table 7.2**, and were used in the land allocation model with the three different UK land use change scenarios to generate the English national, and Y&H regional, targets used as input to the first round of the Delphi. Following feedback from the panel members, *Strategy 3* and *Strategy 4* were defined (see **Table 7.2**) using increasingly more arable and less pasture land, and the land allocation models were rerun.

Table 7.2 Woodland and PEC planting allocation strategies for UK from 2020 to 2050
Showing the percentage of UK planting targets to be allocated to land of each type.

New land use	Land to be planted	Strategy 1 Lowest grade land	Strategy 2: Low grade land	Strategy 3: Higher grade land	Strategy 4: Highest grade land
Woodland	Arable	0 %	5 %	10 %	15 %
	Temporary pasture	5 %	15 %	30 %	35 %
	Permanent pasture	15 %	30 %	50 %	50 %
	Rough grazing	80 %	50 %	10 %	0 %
Energy crop	Arable	5 %	10 %	15 %	25 %
	Temporary pasture	10 %	20 %	40 %	75 %
	Permanent pasture	50 %	50 %	45 %	0 %
	Rough grazing	35 %	20 %	0 %	0 %

7.2 Results from planting allocation model

The results from the planting allocation model (see section 4.4.1), the possible planting targets for England and for the Y&H region, can be seen in **Table 7.3**. Considering planting *Strategies 1 and 2* from **Table 7.2**, the expected areas of PEC planting by 2050 would be between 287 kha and 690 kha in England and 37 kha and 83 kha (or between 3.2 % and 7.2 % of the total agricultural area) in Y&H. As a comparison, the biomass potential assessment of Y&H carried earlier in this research (see section 5.1.1) where it was assumed that PECs could be planted on uncropped bare and fallow land, the land area assumed for energy crops in Y&H was 32,241 ha, just lower than the 37,000 ha needed for the CCC *Further Ambition* scenario using poorest quality land. However, it must be remembered that unplanted land is likely to be considered for tree planting and possibly for restoration as well as for PECS, so actively farmed land would also need to be used for PECS.

The predicted areas of woodland creation needed using *Strategies 1 and 2* are between 185 kha and 524 kha in England and 29 kha and 68 kha (or between 2.5 % and 5.8 % of the total agricultural area) in Y&H.

Considering *Strategies 3 and 4*, using the higher grade land that some of the Delphi panellist favoured, England and Y&H take a higher proportion of woodland and PEC planting. The area of PECS planting in Y&H could be as high as 46 kha (4.0 % of agricultural land) for the CCC *Further Ambition* scenario or 92 kha (8.0 % of agricultural land) for ESC *Clockwork*. The area of new woodland in England could be as high as 537 kha in total, or 18 kha per annum for 30 years, for the CCC *Further Ambition* scenario. This is significantly higher than the 10 kha per annum target set by Confor for woodland creation in *England* by 2030 (Confor, 2019b). The woodland creation in Y&H could be as high as 60 kha (5.2 % of agricultural land) for the CCC *Further Ambition* and ESC *Clockwork* scenarios or 101 kha (8.7 % of agricultural land) for CCC *Speculative*. In total there could be a change of land use of up to 9.2 % of the land in the Y&H region for the CCC *Further Ambition* scenario, the most conservative of the three considered, and this could have a significant impact on the landscape. Not only would planting on this scale need support from governments and landowners willing to adopt change, but it would also require support from the general public to accept the level of landscape change.

The scale of the tree planting challenge for England is clear when compared with the current planting levels. For the CCC *Further Ambition* scenario, between 185 kha for *Strategy 1* and 537 kha for *Strategy 4* would be needed by 2050. In the year 2018–19, 1.4 kha of woodland was created in England (Forestry Commission, 2019b) and if planting continued at this level for 30 years, only 42 kha would be delivered in England.

Table 7.3 Results of four different approaches to allocating the land use changes for three scenarios

		UK	UK	England	England	England	England	Y&H	Y&H	Y&H	Y&H	Y&H	Y&H
Scenario	Allocat-ion strategy	trees planted	PECs planted	trees planted	PECs planted	Silvo-arable area	Silvo-pastural area	trees planted	new trees as % of total agric area	additional PECs area	additional PECs as % of agric area	Silvo-arable area	Silvo-pastural area
		kha	kha	kha	kha	kha	kha	kha		kha		kha	kha
CCC *Further*	1	900	700	185	287	408	360	29	2.48%	37	3.17%	54	42
CCC *Speculative*	1	1,500	1,200	308	493	406	337	48	4.14%	63	5.43%	54	40
ESC *Clockwork*	1	900	1,400	185	575			29	2.48%	74	6.34%		
CCC *Further*	2	900	700	315	345	401	343	41	3.50%	41	3.57%	53	41
CCC *Speculative*	2	1,500	1,200	524	591	394	310	68	5.83%	71	6.13%	52	37
ESC *Clockwork*	2	900	1,400	315	690			41	3.50%	83	7.15%		
CCC *Further*	3	900	700	489	418	394	320	55	4.76%	46	3.98%	52	39
CCC *Speculative*	3	1,500	1,200	805	717	382	271	92	7.93%	79	6.82%	50	33
ESC *Clockwork*	3	900	1,400	483	839			55	4.76%	92	7.96%		
CCC *Further*	4	900	700	537	449	384	321	60	5.20%	44	3.83%	51	39
CCC *Speculative*	4	1,500	1,200	895	769	365	272	100	8.66%	76	6.57%	48	35
ESC *Clockwork*	4	900	1,400	537	898			60	5.20%	89	7.66%		

It can be seen from this modelling that the national and regional impact could vary dramatically depending on the way in which the land use change is allocated. In practice there will be no top-down allocation of land use change. Change will be driven by the relative success of the policies which are designed to deliver woodland and PEC planting (discussed in section 7.4), and it would be hoped that the policies could drive planting on the most appropriate land.

It is assumed in these calculations that there will be significant planting of woodland in Scotland where there is a lower proportion of arable land and higher proportions of pasture, and this assumption is consistent with the greater achievements in woodland creation already achieved in Scotland. This is an advantage of being able to allocate land to its most appropriate use: with Y&H and England taking a high percentage of arable farming, and relying on Scotland to plant trees. However, should Scotland achieve independence, there could be significant impacts on the targets for tree planting in the rest of the UK.

The land-use allocation model was only used in this research to indicate the potential level of change and impact on the local landscape, but it could be developed to assist with setting and tracking local land use change targets. This would be particularly useful in demonstrating to local authorities, or groups advocating tree planting, that many different land uses will have to be accommodated in the UK, and that a balance is required.

7.3 Policies for assessment

The policies included in the Delphi were identified from grey literature and from the stakeholder interviews, and are listed in **Table 7.4**, and the data sources are included in **Table** 7.5. The policies have been allocated to one of the four policy categories in the analytical framework defined in section 4.4.3, by considering the impact on the landowner who makes the decision whether to plant or not. In the majority of cases this allocation of policy type is straight forward, but it one or two cases it may appear to give unusual results. For example, research and development funding delivers knowledge to the landowner so this policy was considered to be an informational policy in this study. It could be argued that because of the expected financial benefit of increased crop yield this policy is an economic one, however, the classification of this policy is not expected to impact the results significantly.

Table 7.4 Policies for review

	Area	Policy	Source	Policy Type
1	General	Develop a single, integrated land use strategy *and* a single countryside and land-use policy covering farming, agriculture, and ecosystems services delivery (balancing carbon sequestration with other priorities including food and timber production).	D, F, L, K, R	Regulation
2	General	Use public money to deliver public goods including evidenced based rewards for climate related activity.	B, F	Economic
3	General	Payments for public goods should be more generous than current schemes and should include an element of profit for the land manager rather than being based on average costs and income forgone.	B	Economic
4	General	Remove any remaining tenancy constraints on change of land-use.	G, K	Regulation
5	General	Ensure that all carbon sequestration activity and public goods delivery (including woodland creation) is treated favourably in tax policy.	B, G, H	Economic
6	Woods	Use a carbon market or trading scheme for land to attract private sector investment and increase the value of woodland creation.	A, E, G, H	Economic
7	Woods	Allocation of land to trees should be a priority of a single land use strategy.	A	Regulation
8	Woods	Set national annual woodland planting targets.	A	Information
9	Woods	Local authorities must set annual planting targets and identify land for trees.	A	Information/ organisation
10	Woods	Deliver government funded advice on woodland creation to landowners and farmers to help remove the divide between forestry and farming.	B, E, H, K, R	Information
11	Woods	Remove the division between forestry and farming in education.	R	Information
12	Woods	Provide long term policy certainty to enable scaling-up of domestic forestry supply chain from nurseries to sawmills rather than a series of 5-year policies.	G, R	Regulation
13	Woods	Woodland creation grants should provide adequate payments for establishment, pest protection and annual payments (to be competitive with other land uses).	B, H, R	Economic
14	Woods	Provide public funding for woodland creation for non-carbon benefits e.g. for flood control, public access or biodiversity.	G, R	Economic
15	Woods	Grant funding should increase with time as progressively better land is required for tree planting.	R	Economic
	Woods	Reduce the bureaucracy of woodland creation: streamline applications and approvals, increase the capacity of administrators, and make regulations simpler (Forestry Act, felling licence regime, EIA requirements).	B, G, H, M, R	Regulation
17	Woods	Reduce the penalties incurred when planting schemes fail.	R	Regulation
18	Woods	New construction developments must include a minimum of 30 % tree cover.	A	Regulation
19	Woods	More forest partnerships like the Northumberland Forest should be formed.	M	Organisation

	Area	Policy	Source	Policy Type
20	Woods	The importance of the commercial market must be recognised in all strategies and policies relating to the forestry and woodland sector.	C, R	Regulation
21	Woods	Improve the public perception of commercial forestry	R	Information
22	Woods	Allow planting of a wider range of species (including conifers and non-natives) to deliver resilience.	R	Regulation
23	Woods	Set targets for the use of UK timber.	M	Information
24	Woods	Remove subsidies for farming land that is more suited to forestry.	H, R	Economic
25	Woods	Expand the UK nationally owned forests including working with public bodies with large land holdings.	H	Organisation
26	Woods	Remove the requirement to replant from terms of felling licences thus removing permanence of land use change.	R	Regulation
27	Agro-forestry	The Government should provide a clear definition of agroforestry, and regulate it as agriculture.	K, R	Regulatory
28	Agro-forestry	The Government should recognise the environmental benefits of agroforestry by including it in public goods environmental schemes.	K, R, G	Economic
29	Agro-forestry	The Government should support the trialling of agroforestry, e.g. supporting independent networks and innovation networks.	K	Information
30	Agro-forestry	Develop a market mechanism to fund agroforestry (e.g. include it in woodland carbon trading).	G	Economic
31	PECs	The government should signal their long-term commitment to bioenergy.	F, R	Regulation
32	PECS	Use demand side instruments to develop and strengthen the market for energy crops, e.g. carbon pricing support for bioenergy with CCS and continued support of biomass generation through existing measures (e.g. exclusion from emission trading scheme obligations).	G, R	Economic
33	PECS	The Government should provide backing for energy crop supply contracts.	R	Economic
34	PECS	Oblige biomass combustion facilities to source a proportion of biomass from the UK with the proportion to rise over time.	G	Regulation
35	PECs	Establish an advisory service for energy crops to disseminate information to farmers.	F	Information
36	PECs	Provide planting subsidies/grants for establishment costs and to replace lost incomes during establishment.	G, F, I, R	Economic
37	PECs	Include grants for establishing PECS in environmental schemes for delivering the public goods of biodiversity, nitrate and flood control.	F, I, R	Economic
38	PECs	Streamline cross-agency approvals of planting PECS.	F, I	Regulation
39	PECs	Support energy crop research and development.	F	Information
40	PECs	Support private sector intermediaries who can raise awareness of financial benefits and arrange long-term contracts between farmers and users.	G	Organisation
41	PECs	Promote the benefits of PECs to the public and local communities.	F	Information
42	PECs	Provide grants to support the development of the full supply chain from planting materials through to harvesting and processing.	F, G, I	Economic

	Area	Policy	Source	Policy Type
43	PECs	Provide grants for removal of the crops at the end of their life.	I	Economic

Table 7.5 Key to sources of policies for review

Reference	Author	Full reference
A	Woodland Trust	The Woodland Trust. 2020. *Emergency Tree Plan for the UK*.
B	CLA	CLA. 2019. *Agriculture, achieving net-zero emissions inquiry: Environment, Food and Rural Affairs Committee.*
C	CLA	CLA. 2009. *Forestry and Woodland Vision and Policy: Seeing the Wood for the Trees.*
D	Energy systems Catapult	Energy Systems Catapult. *2020. Innovating to Net Zero.*
E	NFU	NFU. 2019. *Achieving NET ZERO: Farming's 2040 goal.*
F	D.J. Whitaker	Whitaker, D.J. 2018. *A stakeholder workshop convened by the Centre for Ecology & Hydrology and the Committee on Climate Change. Centre for Ecology and Hydrology.*
G	CCC	CCC. 2020. *Land use: Policies for a Net Zero UK.*
H	Forestry Commission	Forestry Commission. 2019. *Forest Services Board Paper, 24 April 2019.*
I	K. Lindegaard	Lindegaard, K. 2013. *Why we need an energy crops scheme 3*. Crops for Energy.
K	Soil Association and Woodland Trust	Soil Association and Woodland Trust. 2018. *Agroforestry in England: Benefits, Barriers & Opportunities.*
L	CONFOR	CONFOR. 2017. *A Common Countryside Policy Securing a prosperous green future after Brexit.*
M	CONFOR	CONFOR. 2019. *The Future is forestry: Tackling climate change with trees.*
R	Research Interviewees	

Data from Woodland Trust (2020a), CLA, (2019; 2009), Energy Systems Catapult (2020), NFU (2019), Whitaker (2018), CCC (2020a), Forestry Commission (2019a), Lindegaard (2013), Soil Association and Woodland Trust (2018), and Confor (2017; 2019a).

7.4 Analysis of policy Delphi data

The data from both policy Delphi rounds were analysed together and the results are presented grouped by policy area, in the order in which they were discussed with the panel. The results are presented as divergent stacked bar charts followed by a discussion of the panellists' comments. The analytical framework of policy types (regulatory, economic, information or organisation) is used to structure the discussion, during which the policies are identified by their policy number, as used in **Table 7.4**, in square brackets, to enable cross-referencing with the bar charts and table of policy sources (**Table 7.5**).

The divergent bar charts make it easy to spot the policies where there is significant disagreement and where there are significant problems with feasibility or effectiveness. In all bar charts the *no answer* responses have been removed. Generally, *no answer* was gathered where a panellist felt that they did not have relevant expertise, but in some cases panellists were unwilling to provide an effectiveness rating if they had already rated a policy as being undesirable or unfeasible. In keeping with the Delphi method, comments are not attributed to individual panellists in the discussions below.

7.4.1 Land use

Panellist were asked to rate the desirability of seven types of land use. Although this question was included primarily to understand their values, and provide context for their policy ratings, the generally high level of consensus is interesting. Desirability ratings are shown in **Figure 7.1**.

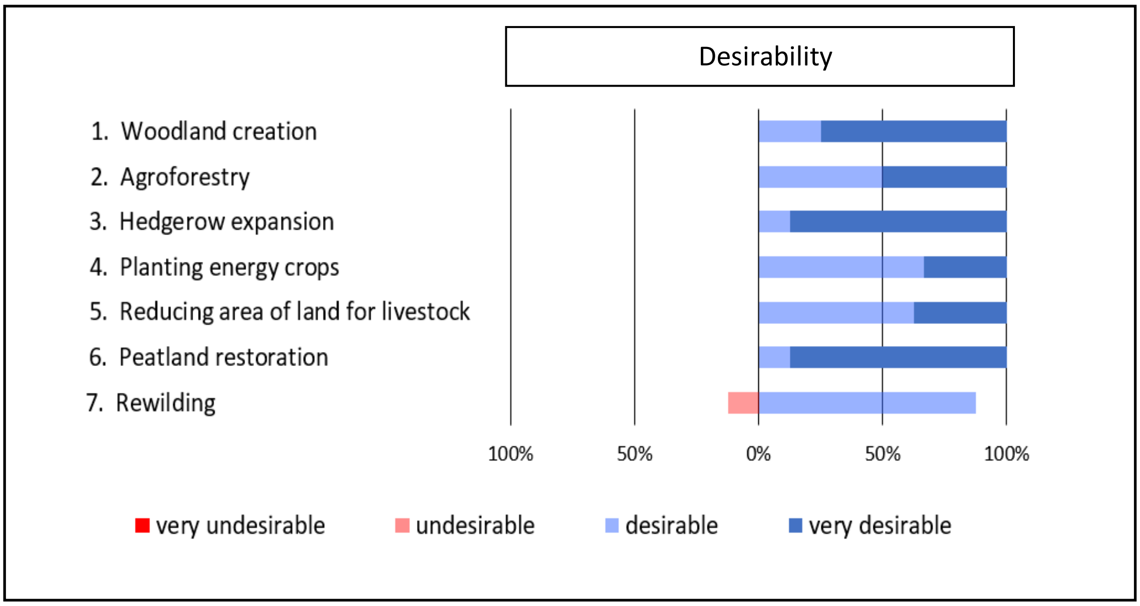

Figure 7.1 Ratings for desirability of different types of new land use.

Peatland restoration and hedgerow expansion were viewed as the most desirable of new land uses to be adopted. Peatland restoration was described as the single most important activity, but it was noted that this receives very little media coverage compared with tree planting. Woodland creation was almost as highly rated, although panellists did warn that it was important to select the right land to avoid negative impacts on habitats and soil carbon, and particularly to avoid planting on peat. However, it was also pointed out that the UK Forest Standard (Forestry Commission, 2017b) should prevent the type of undesirable planting that has taken place in the past.

Agroforestry was highly rated although one panellist had some reservations about the feasibility because it was not a part of the UK culture. This view was countered by others pointing out that the perception of agroforestry as '*stripes*', resulting from alley cropping, is a very narrow view, and that it should be remembered that agroforestry also includes shelterbelts, hedgerows, and woodland pasture, which are all types of accepted land use in the UK. This is discussed in more depth in section 7.4.5.

Reducing the area of land used for livestock and increasing the area of energy crops were both viewed as desirable, but different attitudes to the scale of their adoption appeared later in discussions, see section 7.4.6. In round two some panellists were surprised that the cultivation of energy crops was viewed as desirable by all panellist and had expected more partisan lobbying from the woodland sector. However, there was clearly a consensus that all land use types considered here were part of the solution for net zero emissions

Rewilding was the least supported option and the panellists thought that the term *rewilding* was not well defined, covering a range of activities from managed rewilding to land abandonment, and that a clear definition is needed before it can be regulated or incentivised. One panellist felt that there were better uses for land than rewilding, and another predicted that it could be unpopular with farmers who see their role as managing the countryside. It was recognised by the panel that more research on the carbon balances for rewilding would be needed before including it in plans for GHG reduction.

Three new types of land use were suggested in the first round: hydroponic (soil free) cultivation of crops, better restoration of brownfield land such as landfill sites, and restoring habitats within farms such as field corners. These were considered by the panellists to have only a small contribution to GHG reduction. Hydroponic cultivation of high value horticultural crops would free up a small area of land; however, if some of the highest quality peatland was freed for rewetting then the carbon storage could be significant. Relatively small areas of brownfield land are available and planting on it can be quite challenging because of the poor condition left by contractors. They felt that small scale restoration of farmland was already covered by tree planting and agri-environmental schemes to be delivered by the new ELM scheme (see **Box 8**). In the second round of consultations one panel member mentioned the role that could be played by *paludiculture* (the cultivation of crops, including biomass for bioenergy, on wet and rewetted peatlands (Don et al., 2012; Mulholland et al., 2020)), in providing opportunities for energy crops in the UK.

7.4.2 Net zero scenarios and suitability of land for planting

Opinion on the desirability and feasibility of the three land use change scenarios (**Table 7.1**) was much more diverse. The ratings of the scenarios assessed are displayed in **Figure 7.2**. The CCC *Further Ambition* scenario, the least ambitious of the three, was rated as the most desirable *and* achievable. All the panellist viewed it as either desirable or very desirable, and most rated it as very desirable, with only slight reservations being expressed by one panel member about the area of energy crops. Most felt that that the levels of planting were achievable with considerable effort and policy intervention, and one panel member was very confident that the woodland targets were achievable. Only one panellist thought that this scenario was not feasible, viewing the energy crop planting of 23 kha per annum as unachievable based on the lack of progress in the last 15 years. There was more confidence in the creation of 30 kha of woodland per annum because of the planting levels achieved recently in Scotland, and in the past in England. In the second round of consultation there was a feeling that the level of ambition in the *Further Ambition* Scenario had been discussed long enough for attitudes to shift to the point where it is accepted as realistic: politically, and in the agriculture and forestry industries.

The *CCC Speculative* scenario, with higher levels of PECS and woodland, was rated as less desirable, with objections being raised to the levels of both woodland and PECs planting. The level of woodland planting was viewed as requiring a level of change that would bring about significant and noticeable landscape impacts. This was rated as the least feasible of the three scenarios with some panellists viewing woodland planting levels of 50 kha per annum as unachievable, and others viewing PECs (40 kha per annum) as the problem.

Although the *ESC Clockwork* scenario, with 30 kha per annum of woodland creation and 46 kha of PECs, was rated as desirable or very desirable by most panellists, it received least support because of the level of PEC planting. It was rated second of the three scenarios for feasibility, with the woodland planting viewed as feasible, but with concern about the level of PEC planting. There was one rating of definitely unfeasible because of the impact on the landscape, and the concern that energy crops are less acceptable to the public than woodlands.

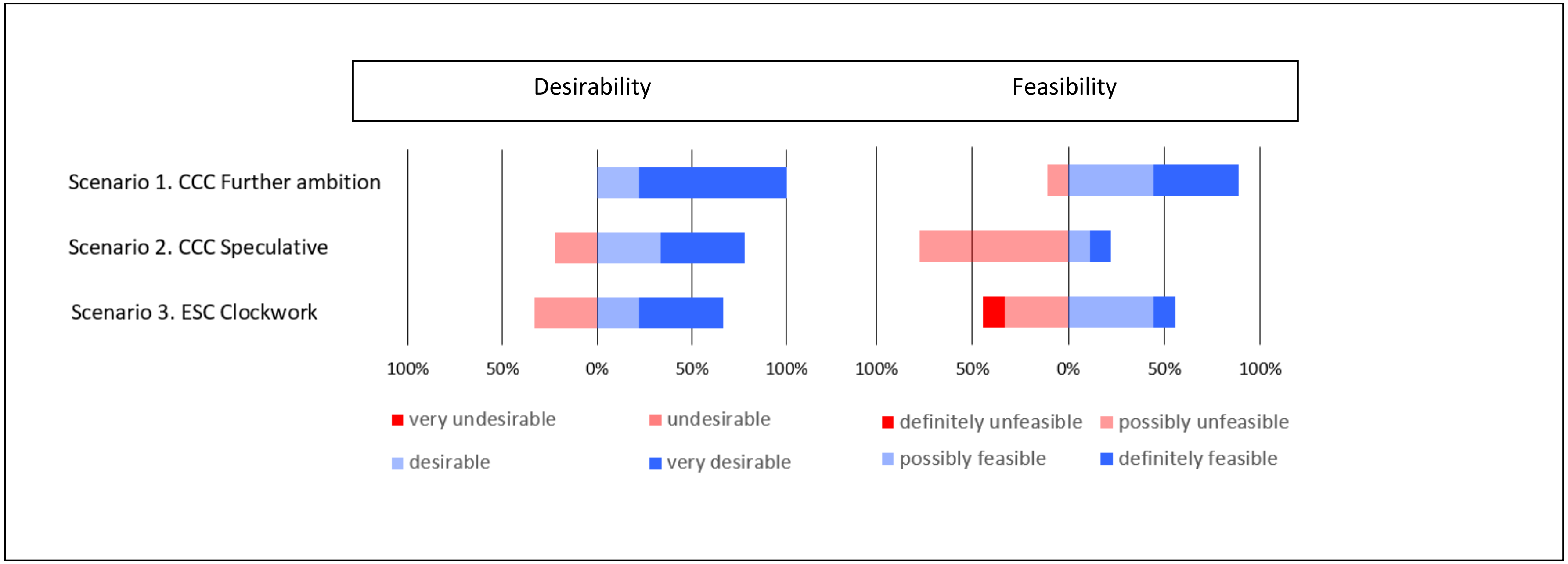

Figure 7.2 Desirability and feasibility ratings of the three land-use scenarios

The overall ratings of the individual land uses and the combined scenarios showed the panellists were reasonably open minded about the types of land use considered, even if their level of knowledge varied between types. Although some of the panellists had clear roles as advocates for woodland creation or energy crops, they all appreciated that many other changes of land use are needed to deliver GHG reduction. The main differences of opinion were over the relative scale of the planting of woodlands and PECS that were desirable.

Although some of the panel members thought that land use *Strategies 1 and 2* used in modelling the distribution of land use change were reasonable, others argued that higher quality land should be used for both trees and PECS. In particular, planting on rough grazing and permanent pasture was viewed as undesirable because of the associated carbon emissions from land-use change. Strategies three and four were defined to incorporate these comments.

7.4.3 Analysis of general land use policies

The panel's ratings of the general land use policies are shown in **Figure 7.3**. These ratings and the comments from both Delphi rounds are then discussed. The number of the policy under discussion is shown in square brackets.

7.4.3.1 Regulatory policies

*A single countryside land use policy [policy 1 in **Figure 7.3**]* was rated as highly desirable, feasible, and effective. Panel members were optimistic that the time was right for the ELM scheme (see **Box 8**) to deliver this in England, following the success of similar schemes in Scotland (The Scottish Government, 2020). However, there was doubt about how this could be made to work. Panellists felt that the decision on land use should ultimately be made by the landowner and there should be no top-down compulsion. There was a fear that ELM could focus on wildlife and miss the opportunity to make carbon sequestration a core delivery, and could also result in farmers having to farm more intensively on their best arable land to compensate for the removal of subsidies.

Although most panellists recognised the barrier that tenancy poses to land use change, *Removing tenancy constraints to land use change [4]* provoked highly polarised responses. Some viewed it as a positive way to overcome the barrier while others viewed it as a highly undesirable policy that could be unfair to landowners and tenants, and could lead to land being taken back in hand, ultimately causing a shortage of tenancies. It was suggested that *amending* rather than *removing* constraints would be a better description of this policy, which would be legally challenging to deliver.

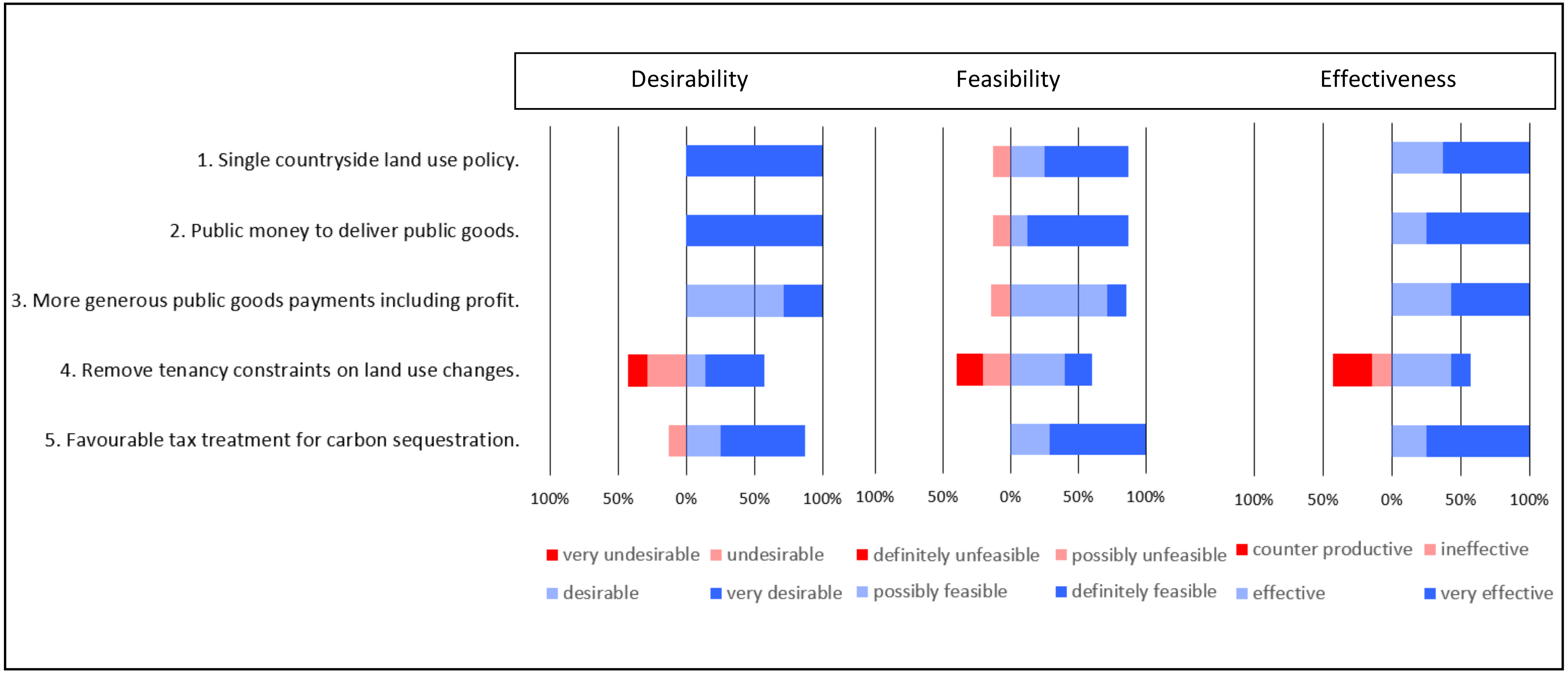

Figure 7.3 Ratings of desirability, feasibility, and effectiveness for general policies

Box 8

The Environmental Land Management scheme (ELM)

ELM is planned to be phased in between 2021 and 2027 covering both agriculture and forestry. From 2024 landowners will be rewarded for delivering public goods of the following types: clean air, clean and plentiful water, thriving plants and wildlife, protection from and mitigation of environmental hazards, beauty, heritage and engagement with the environment, and mitigation of and adaptation to climate changes. National trials of these agri-environmental schemes will run from 2021 to 2024. The ELM scheme will operate at three levels: farm, local, and landscape. Farm level schemes will focus on sustainable farming and forestry practices, e.g. planting buffer strips, soil management, cover crops, and management of pests, water and nutrients (N and P). Local level activities will require cooperation between farmers, landowners or foresters to deliver environmental benefits from larger projects, e.g. tree planting, habitat restoration, natural flood management, rights of way, recreation or education. Landscape scale projects could include activities such as peatland restoration, and forest creation, restoration, and improvement. Lump sum payments may be made to farmers who wish to leave the sector (DEFRA, 2020b).

7.4.3.2 Economic policies

Using public money to pay for the delivery of public goods [2] was another highly rated policy which the Government is expected to deliver with the new ELM scheme. However, to be effective it was argued that the policies need to base the rewards on *evidence* of delivery of fundamental environmental benefits such as carbon sequestration, rather than the '*soft and cuddly'* habitat and wildlife schemes.

Making payments for public goods more generous to include an element of profit [3], was also rated highly but nevertheless provided a range of conflicting comments. While some of the panel argued that it was important to provide an element of profit to reward farmers and to replace the payment previously delivered from EU CAP farm payments, others were not keen on basing payments on profit, and there was concern about whether this money was available.

Delivering favourable tax treatment for carbon sequestration activities [5], although rated as potentially highly effective, would be hard to deliver without unintended consequences because of the complexity of the tax system. The panellists had seen this lead to undesirable outcomes in the past, e.g. poor quality woodland and planting on peat in the 1980s (Crane, 2020; Barkham, 2020; Payne et al., 2018).

7.4.4 Analysis of woodland creation policies

The ratings for woodland creation policies are shown in **Figures 7.4** and **7.5**. These ratings and the comments from panel members are discussed below.

7.4.4.1 Regulatory policies

The proposal that *the allocation of land to trees should be a priority of a single land use strategy* [*policy 7 in **Figure 7.4***], was viewed as being undesirable and potentially counter-productive by many panellists. No preference should be given to trees in a land use strategy, and the best use should be determined individually for each piece of land, with a full range of uses being considered (including food production or peat restoration), and the decision being made by the landowner. Giving priority to trees in all cases could lead to missing the 2050 targets for GHG reduction.

Long term policy certainty to enable scaling-up of the UK forestry supply chain [12] was viewed as vital to succeeding in meeting targets, and confidence has been undermined in the past by policies changing, e.g. nurseries are now unwilling to commit to producing higher levels of stock having been left with unsaleable stock in the past. The panellists thought that continuity is always likely to be a problem, as governments can only supply funding for five-year periods, rather than for the long term, therefore initial investment followed by self-sufficiency was viewed as more likely to be successful than permanent support of the supply chain. Unexpected changes in policies are likely to discourage investment in renewable energy projects (White et al., 2013), while policy certainty or predictability has been shown to be a key determinant of success e.g. the effectiveness of FITs increase when contract durations are increased (Dijkgraaf et al., 2018) with 20 year terms of contracts being effective (Rogge and Reichardt, 2016). The need for governments to retain flexibility in policy conditions, to adapt to changes in technology and markets, must be balanced with the investors need for certainty (Gawel and Lehmann, 2019).

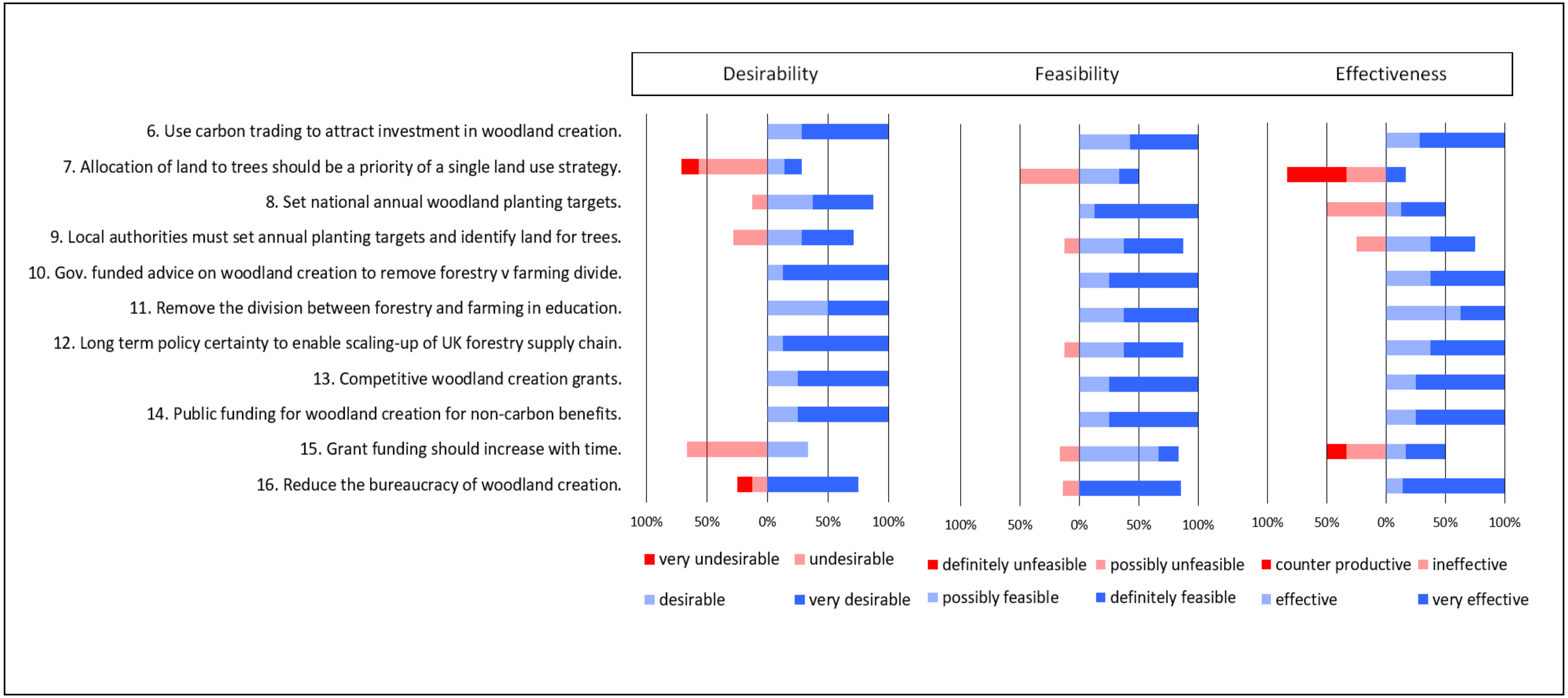

Figure 7.4 Ratings of woodland policies 6 to 16 for desirability, feasibility, and effectiveness

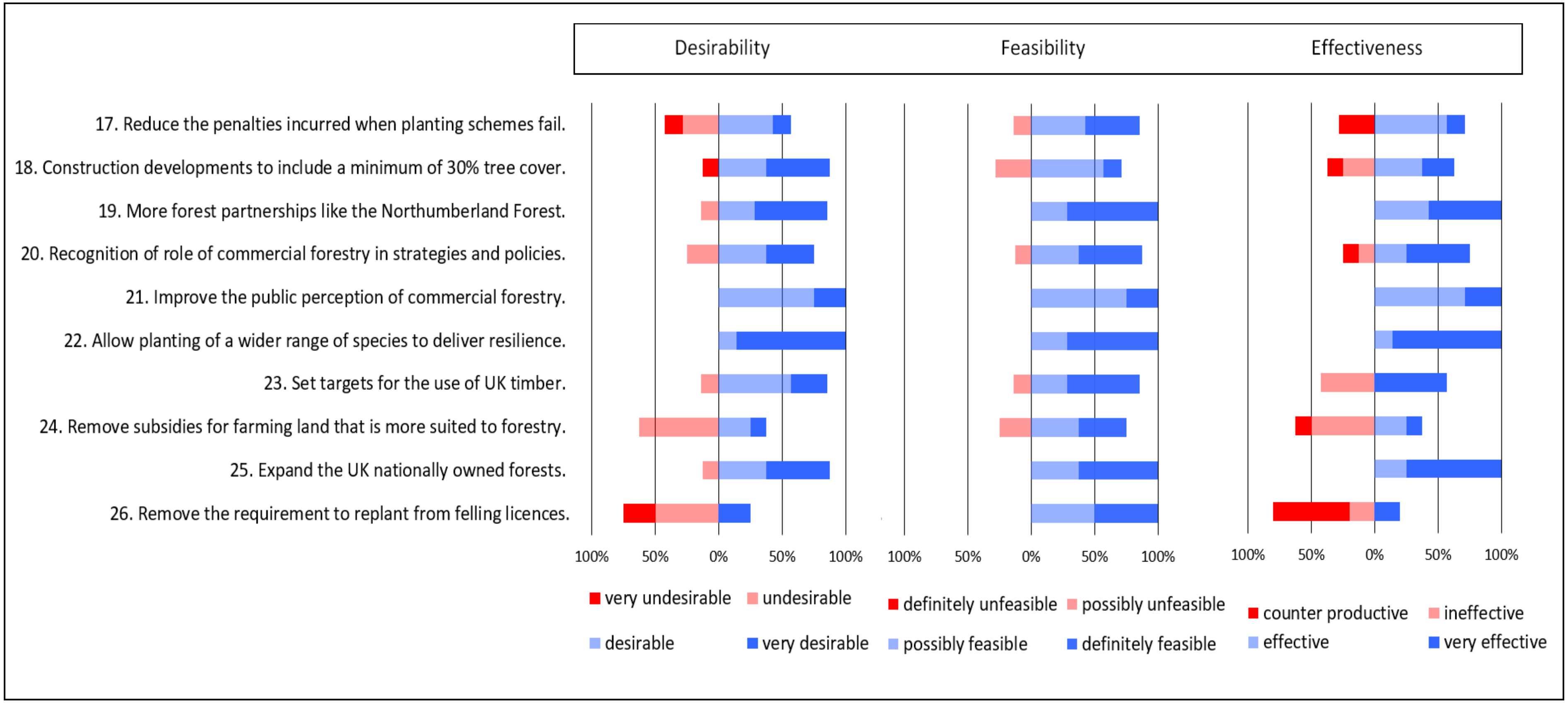

Figure 7.5 Ratings of woodland policies 17 to 26 for desirability, feasibility, and effectiveness

Reducing the bureaucracy of woodland creation by streamlining applications and approvals, increasing the capacity of administrators, and making the regulations in the forestry act, felling licences and environmental impact assessments (EIA) simpler [16] was viewed as a potentially highly effective policy. The success of these measures has already been demonstrated in Scotland (Scottish Forestry, 2020). However, the panel suggested that this policy should have been split into two for assessment. Although the panellists all supported having a more efficient administrative process, there were warnings that the regulations should not be diluted for a permanent land use change where it is important that a rigorous process should be followed.

Although there was sympathy for farmers whose trees fail to establish, there was limited support for *reducing the penalties incurred when planting schemes fail [17]*. It was felt that with good advice and funding it was fair for farmers to bear the risk of failure, thus encouraging high quality planting and management. A good working relationship between landowners and forestry inspectors could help spot problems early enough for remedial action, with penalties remaining as a last resort. If failures did occur despite good practice e.g. because of climate change, then it would be unfair to penalise the landowner.

The suggestion that *construction developments should include a minimum of 30 % tree cover [18],* although viewed as well-intentioned and good for health and well-being, was thought capable of delivering only a small area of canopy cover and could drive up development (including housing) costs. This may not be feasible, particularly on urban sites and there was concern over whether the trees would be well managed. The figure of 30 % and the requirement for trees rather than an environmental net-gain (which is expected to be delivered as a part of the UK Environment Bill (DEFRA, 2019d)) were also challenged. Planting trees on a more suitable site near the development was supported.

Recognising the role of commercial forestry in strategies and policies [20] received wide-ranging responses. Although many felt that commercial forestry is vital in hitting planting targets and to building a timber industry, others considered that there was no need for commercial forestry to be considered in all cases e.g. restoration and biodiversity planting. One panellist commented that considering *productive* forestry rather than *commercial* forestry could highlight the benefit of timber production.

The proposal of *allowing planting of a wider range of species to deliver resilience [22]* was strongly supported, with good information already available from the FC. One panellist thought that the wording should be changed to *encourage* the planting of a wider range of species rather than just *allowing* planting of these species. However, another proposed that more research on performance in different growing conditions was needed, and one was worried about the possible impact of planting in protected areas.

The proposal that *the requirement to replant could be removed from felling licences [26]* was the policy which provoked most comments, with panellists split into two camps. Those who feared that this would be applied to all felling licences were concerned about an overall fall in canopy cover. Whereas those who strongly supported it saw this applying only to ***new*** planting, particularly energy forestry, and one considered it to be the single most important policy to encourage woodland creation, overcoming the reluctance of farmers to permanently change their farm into woodland, by giving the option to revert to farming in the future. Temporary planting on land scheduled for future redevelopment was also proposed as suitable for energy forestry, with permission granted to remove 60 % when development was carried out but retaining 40 % of established trees.

7.4.4.2 Economic policies

Using a carbon market or trading scheme for woodland to attract private sector investment and increase the value of woodland creation [6] was strongly supported. It was viewed as vital in getting the private sector involved, and although some trading is already in place (see section 2.6.5), it was recognised that it is not easy to get this working effectively, and more action is needed from the Government. There could be problems with land price inflation, and speculative investment in land suitable for woodland creation has already taken place. It was suggested that bringing existing woodland into sustainable management should also be rewarded but as this is less attractive to the general public, it is less likely to gain political support.

Competitive woodland creation grants providing adequate payments for establishment, pest control and annual payments [13] were highly rated by panel members. These payments have already been shown to be effective, e.g. applications to the *Woodland Carbon Fund* increased after it was changed to include annual maintenance payments after three or four years. It was suggested that farmers may over-estimate the profitability of their farming activities and that after the removal of basic farm payments forestry may become more competitive. Enforcement to ensure high quality planting and management was supported.

Providing Public funding for non-carbon benefits [14] was also highly rated. There is already funding for trees for flood control and more types will be delivered by ELM, but it was recognised that these non-carbon benefits can be hard to quantify.

The proposal that *grant funding should increase with time as progressively better land is required for tree planting [15]* polarised opinion. Some panel members felt that this would be needed to continue the supply of land for woodland planting, that regular reviews of incentives would be needed, and that the level of grants should reflect the opportunity cost of planting. However, others thought that it could cause planting to be delayed as landowners waited for better grants to become available. It was also felt that there was plenty of land suitable for planting already without the need for increasing grant rates. If rates were too high there could be a risk of planting trees on land that was suitable for other uses such as food production.

Although it is accepted that changes to diet will be needed to reduce GHG emissions, resulting in fewer cattle and sheep grazing in the UK, and that ELM will remove subsidies to hill farmers, it was surprising to see that a policy to *remove subsidies for farming land which is more suited to forestry [24]* proved a very controversial proposal. Panellist were wary of any form of compulsion from the Government dictating how a farmer should chose to use their own land. Choice should always remain with the farmer, and there was even a fear that compulsion to plant trees could result in a deeper division between farming and forestry. It was stressed that a just transition was needed for landowners and tenants, possibly carried out over a period longer than the one planned by ELM (by 2028), carried out with consent of those affected, and with fair financial compensation those forced to leave farming.

7.4.4.3 Informational policies

Setting national annual woodland planting targets [8] was considered to be an informational policy, as this is just an indication of intent unless it is backed up by policies to deliver the targets. Although targets were viewed as desirable, and easy to implement, they were unlikely to be effective, as recent annual targets had not been met. However, it was agreed that woodland planting targets *were* required, and possibly there would be even less planting without them. It was suggested that targets at regional or county level would be more effective in monitoring delivery against target. There is also a risk that targets could deliver inappropriate planting as has happened in the past. One panellist mentioned that targets had to be set as areas of planting or canopy cover and that targets in terms of tree numbers were not appropriate.

Requiring local authorities to set annual planting targets and identify land for trees [9] was a policy which was open to interpretation in different ways. The setting of annual targets without other policies to deliver them was viewed by one panellist as little more than an aspiration, so is also classified as an information policy. Voluntary local targets were supported but there were reservations about local authorities developing their own strategies; it was felt that they didn’t have the instruments to deliver local targets, and delivery would only be possible using the grants delivered at national level. If the land identified for trees was council-owned land, then this could be thought of as an organisational policy, with the councils having the agency to deliver tree planting, and this was rated as a potentially desirable and effective policy. There was opposition to local authorities having the regulatory power to force other landowners to plant trees.

As the cultural divide between farming and forestry is a key barrier to woodland creation the policy of *government funded advice on woodland creation being delivered to remove the forestry farming divide [10]* was rated highly for effectiveness. However, there was disagreement over who should deliver the advice. The FC already partly fill this role but this was not felt to be effective, and there was support for advice being delivered by impartial advisors, commercial foresters, or landowners' organisations such as the CLA. One panellist stressed the importance of information coming from peers: such as neighbours who are already planting woodland, which is consistent with the important role of homologous social contacts in Rogers' theory of DOI, discussed in the woodland interview results (section 6.3.1.1).

Removing the division between forestry and farming in education [11] was viewed as a potentially effective in breaking down the cultural barriers by reaching '*young minds*', and was thought to be more feasible than some policies because it may not need government money.

Improving the public perception of commercial forestry [21] was viewed as difficult to deliver but also potentially effective as public support will be required to deliver increases in planting, and the public needs to understand the social and environmental benefits that are delivered by commercial forestry. Ensuring that quality planting was carried out would improve the image of productive forestry, which is still marred by the evidence of past mistakes.

Setting targets for the use of UK timber [23] was viewed as ineffective by some panel members as there is not enough UK produced timber to meet the current demand and imports are currently needed. With time it was felt that if targets for timber use were aligned with planting targets, then this policy could build more confidence in woodland creation.

7.4.4.4 Organisational policies

Forming more forest partnerships like the Northumberland Forest [19], although well supported provoked divergent comments about the relative success of projects like the National Forest, the Northern Forest as well as the Northumberland Forest. The National Forest (see **Box 6**) has been very successful in creating woodland and a pleasant environment for residents. However, the panellists recognised that these large-scale projects are difficult to deliver, e.g. the Northern Forest has little control over the land or planting and as a result delivery has been slow. Partnerships such as the Northumberland forest (see **Box 6**), with more proactive roles played by the FC and the Government, have demonstrated how effective the partnership model can be. These larger projects were viewed as potentially more effective than smaller, local authority level projects. Some panellists suggested support for projects delivering ecosystem benefits not just forestry, which could be the sorts of landscape scale activities included in tier 3 of ELM (see **Box 8**). One panel member feared that these large-scale projects could deliver too many conifers.

Expanding the UK nationally owned forests [25] was viewed as highly effective and panel members had seen this demonstrated in Scotland, especially in achieving planting in the short term (Forestry and Land Scotland, 2021; Scottish Forestry, 2020). There were some doubts about how much public money should be spent on land for tree planting, the reaction of private landowners and the possibility of distorting the forestry market. It was also suggested that nationally owned diversity forests should be included as well as productive forests.

7.4.5 Analysis of agroforestry policies

The panel's ratings of the agroforestry policies are shown in **Figure 7.6** and their ratings and comments are discussed below.

7.4.5.1 Regulatory policies

*Introducing clear definition and regulation [policy 27 in **Figure 7.6***] was unanimously supported, although participants warned that the regulation should not be too narrow or restrictive, and should cover all the types of agroforestry from alley cropping to shelter belts, and wood pasture. Action is needed soon because the farm subsidies which currently make agroforestry uneconomic will not be fully phased out for another five years. One panellist was concerned that agroforestry regulations could be used to avoid forestry regulations.

7.4.5.2 Economic policies

Providing financial rewards for agroforestry by including it in agri-environmental schemes [28] was well supported. The panellists considered that the benefits of agroforestry had been proven by research and that these should be rewarded. There was less support for *developing a market mechanism for funding agroforestry [30].* This was viewed as unnecessary when there were other mechanisms such as agri-environmental schemes and woodland grants, and there was a risk of undermining confidence in the carbon market for woodlands if low density planting was included.

7.4.5.3 Informational policies

Rather than *trialling agroforestry [29]* it was suggested that *demonstrating* it would be an effective way of encouraging uptake because successful trials had already been carried out.

During discussions it became clear that there are a number of misconceptions about agroforestry, leading to the view that it could have a negative impact on the landscape and is incompatible with UK farming culture. Panellists pointed out that alley cropping, which *would* change the landscape with stripes of trees on arable land, is an extreme type of agroforestry. Hedgerows, shelter belts and wood pasture are also types of agroforestry and they are already a part of traditional British farming, but their role may be overlooked.

A policy is needed to provide agroforestry information and education to farmers and the general public, allaying fears by increasing knowledge of all the types of agroforestry and their benefits e.g. focusing on trees in the very traditional parkland landscape which provide shelter to livestock from heat in summer and cold in winter

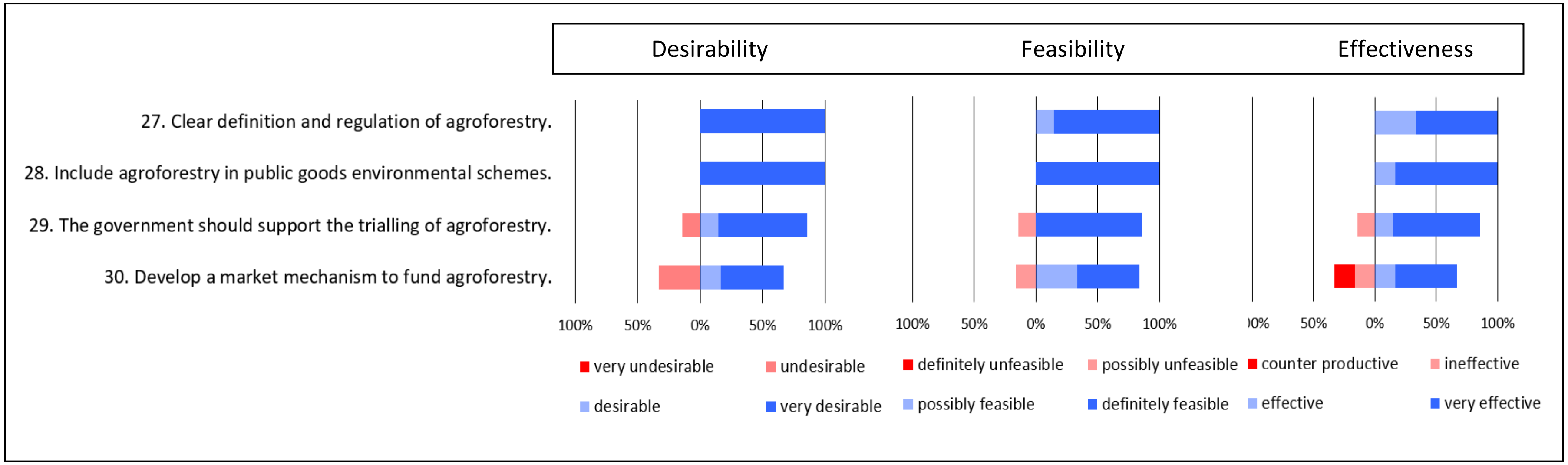

Figure 7.6 Ratings of agroforestry policies for desirability, feasibility, and effectiveness

7.4.6 Analysis of perennial energy crop policies

The panel ratings for the PEC policies are shown in **Figure 7.7** and these ratings and panellists' comments are discussed below.

7.4.6.1 Regulatory policies

*Providing policy certainty for the energy crop sector [policy 31 in **Figure 7.7**]* was viewed as vital in restoring confidence. After a history of support being provided then withdrawn, a clear signal to the power stations is needed. *Streamlining planting approvals [38]* had the potential to encourage higher levels of willow planting but would not be needed for miscanthus. In the long term it could be effective to *oblige biomass combustion facilities to source a proportion of their feedstock from the UK [34]*, especially for new users, but there was the risk of creating counterproductive carbon outcomes by changing existing supply chains.

7.4.6.2 Economic policies

Using demand side instruments to develop the energy crop market through carbon pricing and generator incentives [32] was viewed as the single most effective policy for stimulating the energy crop sector. Injecting investment in generation was expected to create the market for energy crops which could support financially attractive contracts for growers, which would in turn stimulate development of the entire supply chain from plant breeders and suppliers, through to contractors who plant and harvest the crops. Although both policies to *provide backing for PEC supply contracts [33]* and to *develop the full supply chain [42]* were positively rated they would not be needed if generator incentives were effective.

Similarly, *providing subsidies for establishment [36]* of energy crops was viewed as potentially very effective but would not be needed if a sufficiently attractive contract was on offer, and subsidies may not be feasible because of state aid rules. However, some felt that establishment grants may be needed as a short-term measure, or to create parity with woodland creation or other land uses supported by incentive schemes, but they had to be better schemes that the previous UK energy crops schemes (section 2.6.1), which were under subscribed and encouraged poor quality planting. Although the prospect of high costs for removing crops after their productive life has come to an end can be a psychological barrier to planting, it was considered that after 15 to 20 years of income from a contract there should be no need to *subsidise removal [43]*.

Including PECs in environmental schemes rewarding the delivery of public goods [37] was viewed as undesirable by some panellists who thought that there were better uses of land for delivering public goods, such as woodland creation, and that it was hard to quantify the benefits of PECs. Others considered that the benefits of PECS were clear, and that their inclusion in agri-environmental schemes could be more effective than providing planting grants.

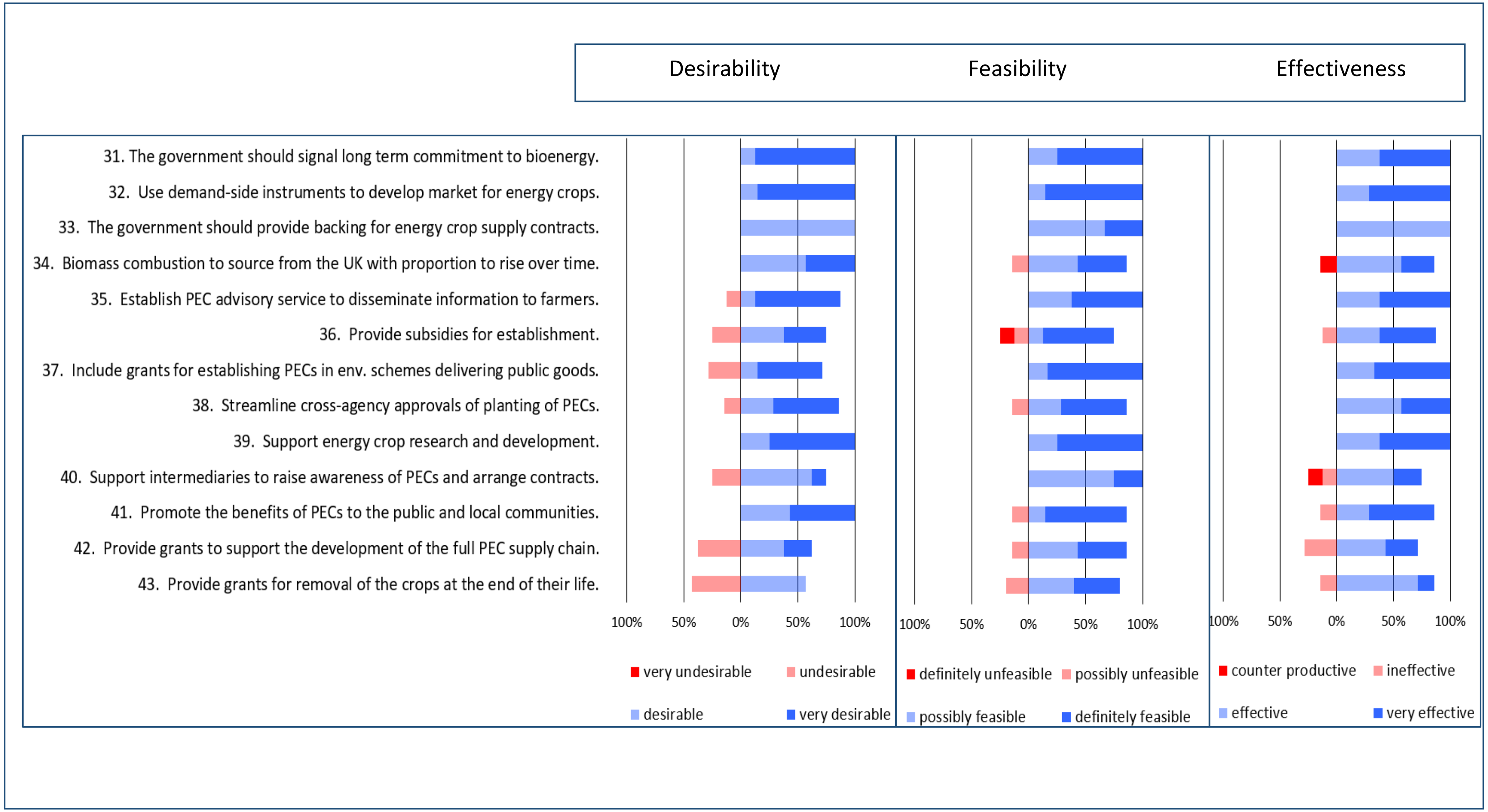

Figure 7.7 Ratings of perennial energy crop policies for desirability, feasibility, and effectiveness

7.4.6.3 Information policies

The three PEC information policies were all rated positively. The *establishment of a PEC advisory service to disseminate information to farmers [35]* was considered to be something that was definitely needed, but some panellists thought it should be delivered by independent advisors who advise on a range of agricultural matters (such as ADAS[9]), while others felt that the private sector could deliver this. *Promoting the benefits of PECS to the general public [41]* was viewed as being less important but it could help overcome the misconceptions that the general public has about energy crops and increase support (see **Box 9**). One panellist thought that it was important to make it clear that using energy crops is not deforestation.

As relatively new crops it was felt that there was still a lot of potential for improving cultivars to increase yield and research is needed on climate resilience, so there was strong support for *government money to support energy crop research and development [39].* In particular, government support and international cooperation are needed for breeding research, where the long breeding cycles make commercial research unfeasible, and thus continuity of funding is important.

Box 9: Public perceptions of energy crops

In 2020 members of the public in the CCC Climate Assembly (Climate Assembly UK, 2020b) were not strongly supportive of biomass energy, with only 40 % rating it as desirable, significantly lower than ratings for offshore wind (95 %), and solar (81 %), but more popular than nuclear (34 %), and fossil fuels with CCS (22 %). When they were consulted on land use, 99 % were in favour of tree planting but only 42 % supported growing biomass for BECCS (Climate Assembly UK, 2020a).

Government tracking of public perceptions of using biomass for energy (BEIS, 2018b) showed support increasing from 64 % in 2012 to 69 % in 2018, much lower than support for solar and wind generation. This survey also showed that awareness of CCS was low and was supported by only slightly above half of the public.

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[9] ADAS is an independent agricultural and environmental consultancy and provider of rural development and policy advice which was formerly a government agency (The Agricultural Development and Advisory Service).

7.4.6.4 Organisational Policies

The policy of *supporting intermediaries to promote PECS and arrange contracts [40]* prompted divergent responses. Some panel members thought that this should not require government funding, as the promotional role was already being filled by private sector companies such as Iggesund and Terravesta. They felt that arranging contracts was a role that power stations could fill. However, another panellist proposed that the promotion of energy crops should be carried out by an independent organisation, not tied to breeders or contract suppliers.

7.4.6.5 Summary for PECS

In summary, the panellists proposed that by far the best way to revive the energy crop sector was for the Government to deliver the right financial incentives, or investment, to generators together with creating policy certainty. This should allow the generators to offer attractive long term biomass contracts to farmers, directly or through intermediaries, with no need for long-term incentives for growers, and no further intervention in the supply chain. It was acknowledged that planting grants could be needed initially to make planting competitive with agri-environmental schemes and to build some momentum in the sector. Recognising the positive environmental impacts of PECS and including them in agri-environmental schemes was supported by some of the panel members. Information policies would be desirable and effective, supplying information and changing the perceptions of farmers and the general public, and further support for research into breeding and cultivation is needed.

7.5 Reflection on use of the policy Delphi method

The policy Delphi allowed the rapid assessment of policies by a diverse group of panellists. It would have been impossible to consult with all the participants in a single meeting because of the demands of their workload. It also allowed consultations to start very quickly after recruitment, allowing less time for participants to drop out. However, each round stretched out over several weeks to allow all participants to take part, and there was the temptation in the first round to try to recruit more panellists, and in the second round to wait for reluctant participants before moving on to the next step. A balance had to be struck between maximising participation and maintaining momentum.

The approach taken here of the researcher gathering policies for assessment (see section 4.4.5), thus removing the need for a data gathering round, made good use of the limited time available from the experts and allowed them to focus on the core activities of rating policies, justifying their opinions, and identifying issues and possible counterproductive effects.

Another benefit of the method was that by issuing condensed results from the stakeholder interviews to the expert panel, their positive feedback validated the results of this earlier research.

As well as rating policies and identifying potential side-effects, the policy Delphi identified those policies where opinions differ widely, and those which are potentially unpopular politically, with the stakeholders affected, or with the general public, and will need particularly sensitive implementation. The researcher found the role of impartial facilitator frustrating at times: not being able to add analysis to the first-round report, having to give all contributions equal weight and remaining impartial in all discussions. However, she sometimes adopted the role of '*devil's advocate'* in the second round to support the arguments of other panel members, and this partly overcame the lack of interaction between panellists.

Attrition and recruitment have both been discussed above in section 4.4.5.5. The effectiveness of a policy Delphi is reliant on recruiting an expert and well balanced panel, and although there were key absences (BEIS and DEFRA), feedback from the participants suggests that a balanced composition was achieved. Losing only one panel member between rounds one and two was considered to indicate successful application of the process, and confirm that most of the participants viewed the process as worthwhile.

The policy Delphi proved to be an effective way of analysing a large number of policy suggestions, and identifying the potential problems in their delivery and application. During a pandemic all types of Delphi could become more popular methods of collaborative working or research, providing the opportunity to gather richer data than is possible in video conferencing. However, the policy Delphi is not just for times of social distancing: it is a valuable technique which makes effective use of limited access to experts and provides the opportunity to gather personal values and opinions in a way that is not possible in any group discussion.

7.6 Policy conclusion

This chapter has answered the final research question: '*What policies would be effective in increasing the production and use of biomass for bioenergy to help meet the UK's net-zero target?*', by identifying a mix of policies and rating them using a policy Delphi.

The woodland creation target of 30,000 ha per annum was viewed by the panel as being achievable, with a lot of effort, despite being considerably higher than the levels achieved in recent years. The key to delivering this level of planting is to offer landowners financial incentives that provide replacement for the income foregone by abandoning the traditional annual incomes available from farming. The *Woodland Carbon Guarantee* (section 2.6.3) could be one way of delivering the income but the Government budget is currently limited to £50 million for this scheme, and further development of carbon trading for woodlands is needed to attract large scale investment. Grants need to be easier to apply for, but this should not mean that standards for woodland creation should be lowered. The stakeholder interviews (see Chapter 5) identified that farmers are reluctant to change their land from arable or pasture as they fear devaluing their land but the removal of EU farm subsidies and the introduction of ELM may radically alter land values, possibly removing this barrier. Information provision from trusted sources and education both have an important role to play in tackling the social and cultural barriers to woodland creation and the cultural divide between farming and forestry. Although small community projects in urban areas make valuable contributions to wellbeing and the environment, they make little contribution to the 30,000 ha per annum planting targets. Much of the large-scale planting needed to hit the target will have to be productive forestry: either commercial operations or part of the nationally owned forest. The new policies announced by the Government in Spring 2021, including leasehold partnerships, and the England Woodland Creation offer, may deliver some of the key policy features identified here as being vital to increased planting (DEFRA, 2021b).

Agroforestry needs to be regulated so that farmers can be supported by either forestry or agri-environmental grants, and the policy Delphi process identified the need for a policy to promote knowledge of agroforestry and its benefits to landowners and the general public.

The clear recommendation for encouraging PEC cultivation is to deliver policies at the top of the supply chain, to encourage the development of generation capacity which can at some point deploy CCS. By creating the demand for biomass, the whole supply chain can be stimulated, and although direct support for farmers of PECs may be needed this should only be for a short period. The assumption was made during the Delphi discussions that combustion would be the preferred process for BECCS rather than gasification or pyrolysis; this may not be the case in practice, but it would be advisable to use proven generation technology rather than repeating the mistakes of the ARBRE project (see section 3.4). Some way needs to be found of rewarding the negative emissions from BECCS which are currently not covered by emissions trading schemes. It is worrying that there will not be a new UK biomass policy until 2022, and that currently there is much less public support for PECS than for other types of competing land use (see **Box 9**). The challenging planting targets recommended by the CCC, together with the lack of any signal from the Government that PECs will be promoted, means that it is hard to imagine significant planting in the next five years, despite confidence among the panel members that BEIS understands the contribution that PECs could make. This concern was confirmed by the CCC in their sixth carbon budget announced in December 2020 (CCC, 2020e) which contained the modest target of 23 kha of energy crops by 2025.

It is vital that the new ELM system delivers a single land-use policy that is balanced to support *all* the desired changes of land use: woodland, agroforestry, PEC, food production, habitat restoration and other environmental schemes. To expand the maxim that it is important to plant '*the right tree in the right place'*, it is important to have the right *land use* in the right place. There is a danger that the strong public sentiment for woodland creation and rewilding, and the lack of public and government support for PECs, could lead to a failure to provide balanced policies. Mistakes could lead to missing GHG reduction targets because of a shortfall in biomass, and exporting emissions if food production is displaced from UK farms to countries with higher emission practices. As Warren et al. (2016) observed, PECS are at the ' *interface between agriculture, forestry and energy policies*'. The division of responsibilities between government departments makes it more difficult to coordinate policies: DEFRA is responsible for forestry and farming, and BEIS for energy crops, the FC assists with planting advice and some grants but other payments are delivered by the Rural Payment Agency, and Natural England regulate some schemes. Konadu et al. (2015) warn that setting targets for energy crop cultivation will create competition for land use and if these are not formulated in conjunction with overall projected land use changes, physically unfeasible land use targets can be set for energy crops. This argument could be extended to woodland creation targets too.

One recurring theme in the discussions with panel members was the importance of designing policies which would not make landowners feel that they were being coerced into actions that they were not comfortable with, such as permanent changes to land use or tenancy terms. It will be important to have willing participants in the major changes required over the next 30 years. The panel members also recognised the importance of non-financial motivations in the design of effective policies, as highlighted by Warren et al. (2016). The informational policies tackling issues such as the divide between forestry and farming and the need for greater knowledge of new practices are important components of a well-balanced and effective suite of policies.

Chapter 8 Conclusions

The aim of this research was to assess the prospects for increasing the UK production of bioenergy feedstocks. It used a novel approach, researching energy crops and woodland in the same study; using a regional biomass assessment, stakeholder interviews and a policy Dephi. The results show that perennial energy crops and woodfuel have the most potential for increasing the UK supply of biomass, but there are many barriers preventing their production. These barriers could be overcome with appropriate government intervention, and policies to increase biomass production are proposed. The key findings, the answers to the three research questions, are summarised below, then the implications of the research are discussed. The potential to apply these findings outside the UK is assessed, and future work to fill the many knowledge gaps that emerged as this research progressed, is discussed.

The concluding remarks highlight the UK Government's role in delivering policies to build a strong bioenergy sector that can deliver negative GHG emissions.

8.1 Summary of research findings

8.1.1 Types of biomass with potential for greater production or use

'Which types of biomass have potential for increased production or use in Yorkshire and Humberside?'.

PECs were found to have the greatest biomass potential, and they have been proposed as bioenergy feedstocks for many years. At the time of this assessment (2018), the prospects for these crops looked bleak, but since then the Government has committed to net zero GHG emissions by 2050, and the IPCC (IPCC, 2018) and CCC both support using PEC biomass for BECCS to deliver negative emissions. BEIS is assessing the readiness of the PEC supply chain for scaling up production, and is consulting on a new bioenergy strategy, indicating that the Government is taking bioenergy seriously and preparing to act. The biomass potential for woodfuel was lower than that of energy crops, but there is already a market and a supply chain for woodfuel in the UK, with demand partly met by imports, so there may be scope for expanding this market or replacing imports with domestically produced biomass. Recent efforts to create woodland and increase woodland management have been disappointing, but with more managed woodland, Y&H would have the potential to produce more sustainable woodfuel. Poultry litter is the agricultural by-product with most potential for increased use.

In contrast, municipal biomasses (MSW, landfill gas, waste wood and sewage sludge) offer little potential for further use in Y&H, as processing plants are either in place, or under construction, for most of the biomass arising. Straw has little potential for increased exploitation because of competing demands and high prices, but more pig and cow manure could be used if the AD industry expands and the use of waste feedstocks are incentivised.

Many statistical biomass assessments have been carried out at a national, continental, or global level, but few at regional level. The last assessment for Y&H was ten years ago (AECOM, 2011), when substantial demand was predicted for co-firing with coal, and before significant growth in the AD industry. A regional assessment, especially one carried out at local authority level (as in this study), could provide valuable information on the size and location of potential sources of feedstocks, and assist with planning the optimum locations of generation facilities.

8.1.2 Barriers and drivers to biomass production and use

'What are the barriers to, and drivers for, the greater production and use of biomass for energy production?'

No insurmountable technical problems were found with PECs, but barriers to cultivation include the establishment costs, long period of commitment, lack of income for two or three years after planting, cultural barriers to non-food crops, and lack of confidence in PECs following previous cancellation of contracts and removal of government support. The main barrier is a lack of contracts; and without secure, long term contracts, at a price that can compete with cereal crops, farmers will not plant PECs.

The permanence of woodland is a significant barrier to its creation, requiring the cultural change from being a farmer to being a woodland owner, and removing the option of farming that land from future generations of a family. Most farmers are not comfortable with this change. The high initial costs of planting and protecting woodland, and loss of annual farm income are also major barriers.

The RHI scheme has driven the price of woodfuel up to levels where woodland management is now financially attractive even for small woodlands, and management in Y&H has increased, although this increase has not yet been reflected in FC statistics (Forestry Commission, 2020a).

Strong demand for poultry litter as an organic fertiliser is constraining the supply for energy generation, and on-farm litter combustion, with high capital costs, and strict regulations, is attractive to only the largest farms. The litter supply could increase in line with any future growth in the poultry sector and tightening litter storage and spreading regulations would create disposal problems, increasing the supply for bioenergy. Demand from AD could increase as new incentives for biomethane production (BEIS, 2020c) lead to expansion of the sector and wastes and by-products are favoured over energy crops as feedstocks (CCC, 2020e).

The novelty of this research is in investigating annual and perennial energy crops, woodland creation, and woodland management in the same study, allowing trends in decision making to be detected, highlighting the importance of the permanence of commitment, the risk involved, and the deviation from accepted practice. These factors explain the easy acceptance of crops for AD, and the failure to plant PECs and woodland at scale.

8.1.3 Assessing the policies needed to deliver biomass

'What policies would be effective in increasing the production and use of biomass for bioenergy to help meet the UK's net-zero target?',

A *single, effective land-use policy* was viewed by the Delphi panellists as the most important policy they appraised. The post-Brexit ELM scheme will need to fulfil this role in England, rewarding public goods delivered by landowners, ensuring that suitable land is used for PECs, woodland, and habitat restoration, while also maintaining food production. The policies must be acceptable to all stakeholders, especially landowners but also to the general public, all the government departments and agencies involved in formulation and delivery (including DEFRA, BEIS, DfT and FC) should collaborate to deliver compatible and complementary policies.

The most effective way to create demand for PECs is policy intervention at the top of the supply chain. Investment, subsidies, or rewards for negative emissions are needed to encourage power generators to invest in large scale bioenergy plants with CCS. This will allow generators to offer long-term biomass contracts which will in turn stimulate the development of the full supply chain. Direct crop subsidies may be needed for a short period to overcome some of the initial barriers to planting, and rebuild confidence in the crops.

Many woodland policies were rated highly for their potential effectiveness including planting grants with annual payments, agri-environmental schemes rewarding the public goods delivered by woodlands, and education and information for landowners.

Although many policies for increasing UK biomass production have been proposed by researchers and lobby groups, recommendations are generally made for only one type of biomass. By considering policies for energy crop cultivation *and* woodland creation together in this research, and involving policy experts from both sectors in assessing them, it was possible to understand the potential conflicts between the two types of land use, and the risk that policies could inadvertently encourage one type of land use at the expense of the other.

8.2 The implications of the research findings

Bioenergy has been a part of the UK's efforts to reduce GHG emissions since the 1990s, and it currently delivers 8.1 % of the UK energy supply, with the largest contribution provided by biomass imported for power generation (BEIS, 2020b, p. 11) e.g. at Drax. In the past, bioenergy was used to deliver reductions in GHG emissions by displacing fossil fuel use, but now the UK has committed to reaching net zero GHG emissions by 2050, bioenergy has a more important role to play: delivering negative emissions as a part of BECCS. The area of PEC cultivation in the UK is still under 10 kha, with no meaningful increase in the last ten years (DEFRA, 2020a). Woodland creation has also been disappointing, with repeated failures to meet woodland creation targets. The CCC scenarios for meeting the net zero target require significant woodland creation, and a dramatic increase in the cultivation of PECs (CCC, 2020e). Because of this history, the levels of land use change modelled in CCC scenarios could be viewed as not only ambitious, but unachievable. Now the three research questions have been answered, it is possible to draw on all the results, to discuss the prospects for producing biomass in the UK, and to understand how these targets can be met.

8.2.1 Prospects for perennial energy crops

Maize and grass for AD are currently much more popular energy crops than PECS, but in the long term maize cultivation for AD is likely to end, to reserve high quality land for food production, and AD feedstocks will be limited to wastes and by-products, leaving PECS as the only energy crops cultivated in the UK (CCC, 2020d). Biomass from 700 kha of PECS (as proposed by the CCC *Further Ambition* scenario) could supply 10.5 million odt of biomass or 19 TWh of electricity annually in the UK: enough to supply 86 power stations the same size as Brigg (40 MW), or supply the current demand for biomass from Drax power station. Depending on how the PECs are distributed, the Y&H region could grow as much as 44 kha: enough to support five 40 MW power stations.

Since support for PEC planting (ECS and ECS2) was removed, the crops have appealed to only a small segment of farmers: those in an area with a market, who will forgo short term income in return for a long term, guaranteed income for a low input crop, often planted on an awkward area of land. However, if the Government wants PECs at large scale, then there *are* potentially effective policies to deliver them, and the most effective is likely to be intervention at the top of the supply chain.

After repeated setbacks to their fortunes for more than 20 years, further attempts to promote PEC cultivation in the UK will have to succeed where previous attempts have failed, but there is currently a perfect opportunity in the UK. The replacement of the CAP farm payments with ELM will result in dramatic changes to farm incomes, forcing changes to farming practices and landscapes during the transition period (2021–27). As farmers look for new sources of income, well priced, guaranteed contracts for PECs could offer economic advantage at an acceptable level of risk. If the Government accepts the advice of the CCC and supports PECs, then there may finally be the level of support needed for planting at scale, but if support comes too late, farmers may already have diversified into woodland or agri-environmental schemes.

This research assumed that biomass would be used in BECCS. Although this is consistent with current CCC advice, it will not be certain until the 2022 biomass strategy is issued. However, the barriers to energy crop production and policies to overcome them will be independent of the end use. If planting targets are set significantly higher than 700 kha, and towards the 1,400 kha of planting included in the more ambitious *ESC Clockwork* scenario, then barriers may be harder to remove, and policies assessed in Chapter 7 may not be capable of delivering at this scale.

8.2.2 Prospects for woodfuel and woodland creation

The prospects for woodfuel are more difficult to predict. The supply was not quantified in this research, but it is assumed that it will increase if woodland creation (including agroforestry and energy forestry), and woodland management are increased. Poorly managed broadleaf trees which have suffered damage from pests and diseases, could generate a sizeable supply of fuel. Planting will not guarantee useable biomass unless owners are willing to thin or fell some or all of the wood, and the harvesting date of wood is unpredictable. There will be competing demands for wood for construction, furniture, pulp, or board, and there may also be public pressure to preserve the standing wood, or to prioritise long term carbon storage by using wood in construction. Following high profile campaigns to mitigate climate change by planting trees, using those trees for energy could face opposition from many quarters.

There is currently strong public and political support for woodland creation but turning this into planting has not been successful, because landowners have not found it an attractive option for their own farms or estates. The results here suggest that there are many effective policies to deliver woodland creation, in particular better grants should deliver more planting, but permanence of planting is likely to remain a huge barrier for farmers to overcome, so shorter term crops such as PECs may be favoured.

8.2.3 Prospects for increasing UK production of bioenergy feedstocks

In conclusion, this research shows that if the Government is serious about meeting the latest carbon budgets on the path to net zero, and if bioenergy forms part of this plan, then there are potentially effective policies which could deliver the levels of PEC and woodland planting in the *CCC's Further Ambition scenario.* A combination of financial incentives, regulation, education, and direct intervention should deliver the desired changes of land use. The policies will have to be carefully designed to deliver balanced change, delivering the right land use in the right place. They also need to take farmers willingly through significant changes, and overcome public opposition to bioenergy and the associated changes to the landscape. It is important that policies stimulate demand for UK biomass, not an increase in imported wood pellets.

The Delphi panellists unanimously believed that an effective ELM scheme is vital for delivering all land use changes needed to reach net zero. It must deliver a suite of policies to shape a completely new way of managing the land in the UK, moving away from rewarding those with land at their disposal, to rewarding the delivery of public goods. It will affect farm livelihoods, land values, farming practices and the landscape. Among a host of other demands, it will have to deliver a regime under which both woodland creation and PECs are sufficiently attractive for farmers and landowners to adopt them: offering a financial advantage at an acceptable level of risk.

The Government must clearly signal their intentions during the ELM transition period, while farmers seek to replace their CAP income. Reassurance has been given that, by planting woodland, farmers will not miss out on future incentives(Forestry Commission, 2019c). Following the definition of the UK biomass strategy, similar backing for PECs would be desirable to build confidence in the crops.

This research focussed on the role of farmers and landowners as decision makers in the delivery of biomass. It is possible that scaling up bioenergy could be hampered by problems elsewhere in the supply chains. In the same way that the ARBRE project failed because of problems with gasification technology and funding (Piterou et al., 2008), BECCS projects could fail because of issues with gasification or CCS technology, or if bottlenecks occur in deliveries of young trees, rhizomes or other planting materials. No serious issues with PECs were raised by the research participants, but the risks of shortages of nursery stocks for trees and of skilled forestry staff were identified. BEIS is now reviewing both supply chains (Ricardo, 2020). If BECCS is to successfully deliver negative emissions, CCS will have to be deployed at a scale which has yet to be proven. Investment in the UK (Prime Minister's Office, 2020) and Norway (Mavrokefalidis, 2020), and implementation in the US (Beck, 2020) are encouraging, but uncertainty remains. Without CCS the case for thermal processing of wood biomass for electricity generation is less compelling, but energy crops grown for bioenergy without CCS may be easier to justify to critics, because of the shorter carbon debt (see section 2.3).

The biomass strategy for the UK will have to be reviewed regularly in light of progress against the carbon budgets, technology developments in all energy sectors including BECCS, progress in crop breeding, the introduction of novel crops, new pests and diseases, and the impact of climate change on crops. Bioenergy and land use policies will have to be constantly monitored and adjusted to keep progress on track.

8.3 Application of results to other regions and countries

The stakeholders interviewed in this research were predominantly from Y&H, but had experience and knowledge of the whole of the UK, and were aware of few regional differences. Y&H proved to be a particularly good region for energy crop research because of the extensive experience of past and current growers. It was concluded that the interview findings are applicable to most of England and Wales, and some apply to all of the UK. The generalisation of these results is limited by the regional restriction on maize cultivation and the divide in the attitudes to forestry: commercial forestry being concentrated in Scotland and the North of England. The Delphi panellists were all knowledgeable about all of England, and in some cases, all of the UK. The Delphi assessed policies needed throughout the UK, but for devolved matters (e.g. forestry and agriculture), the assessment focussed on England.

Many EU countries have set woodland creation targets, and most have seen increases in recent years (Forest Europe, 2020). Woodland creation in the UK may face more cultural barriers than in many other countries because of our low canopy cover, and lack of widespread commercial forestry. Nevertheless, some of the woodland creation research may be relevant to other countries with low tree cover, such as the Republic of Ireland, which has increased cover from a low of 1 % through a combination of state planting, and incentives for landowners (O'Leary et al., 2000), to 11.4 % in 2020 (Forest Europe, 2020).

Miscanthus adoption in other European states has been even lower than in the UK, with small areas planted in France and Germany (Ben Fradj et al., 2020), Poland, and Italy (ADAS, 2016), and a new miscanthus powered heat network in Moldova, (Bioenergy Insight, 2021). Research into willow and SRF adoption in Sweden, which led the way in early European planting, identifies barriers to adoption which are similar to those identified in this research (Mola-Yudego et al., 2014; Mola-Yudego and Gonzalez-Olabarria, 2010). Mola-Yudego (2017) recommends that strategies should be set at national or sub-national level to realise local woodfuel potential. The policy Delphi generally discussed policy setting at national level but panellists were in favour of more local initiatives like the National Forest and Northumberland Forest which had already proved to be successful.

There may be some scope for other countries, particularly in Europe, to benefit from the findings of this research, but as Cross (2021) concludes, each country has a unique landscape of environmental, regulatory and energy factors that mean that it is hard to extend the lessons learned from bioenergy policy implementations from one country to another.

8.4 Future work

The most significant omission from this research was a rigorous projection of the UK woodfuel supply, needed for planning future generation capacity, and demand for imports. This assessment is a considerable undertaking, requiring input from the FC in all four home nations: data on planting, species mixes, future growth rates, and management plans. Projections of planting, demand for timber, wood products and woodfuel, and the pressure to leave mature timber in the ground would all have to be modelled. In particular, the supply of woodfuel from poorly managed and pest-damaged broadleaf trees should not be overlooked.

Little evidence was found of SRF (energy forestry) from the stakeholder interviews, and there is scope for researching the level of interest in the UK, the potential for delivering carbon sequestration and fuel, and the likely opposition to non-native planting from environmental campaigners.

The potentials for cow and pig manure were not researched, because of the greater flexibility of poultry litter and the lack of activity in the AD industry at the time of the interviews. However, there may be scope for exploration of their potential in light of renewed government support for biomethane (BEIS, 2020c).

As the stakeholder interviews were dominated by farmers of lowland, family-owned arable farms it would be useful to carry out more research with hill farmers, including tenant farmers, to get a better understanding of their attitudes to ELM, and to the prospect of changing their land from pasture to energy crops or woodland.

The assessments of policies did not include their calibration. Incentives need to be high enough to encourage participation but must ensure cost-effective delivery of natural capital, ecosystems services such as flood control, carbon sequestration and recreational facilities; an economic assessment is needed of the policy costs and the value of the services delivered.

This research focussed on farmers and landowners, but before PECs and trees are planted at the scale required, the whole supply chain must be examined, from seed or rhizome production through to processing plants. BEIS announced in March 2021 that they have initiated this work (Ricardo, 2020) and have launched a biomass innovation programme (BEIS, 2021a) to encourage innovation projects, initially limited to nurseries and farms.

Another area where significant research could be carried out is carbon taxing and carbon trading, and how negative emissions from direct CCS or BECCS, and the sequestration of carbon from woodland creation, and habitat restoration can all be fairly rewarded.

The model of land use change developed here could be expanded to include habitat restoration and settlement expansion. This could be used with data from habitat maps being delivered by the Environment Bill 2020 (DEFRA, 2020e), to model the land use change required in more detail for different regions, identify specific conflicts for land use and help set local planting targets which are consistent with a UK land use strategy.

When more is known about the ELM scheme and any extension to, or replacement for, RHI is announced, the impacts should be investigated. The impact of the Northern Forest, and its ability to obtain land, should be assessed as the project progresses, comparing progress with the National Forest and the Northumberland Forest, to understand which approach is most successful at delivering increased canopy cover.

Public attitudes were identified by the Delphi panellists as an important factor in creating an environment in which policies are formulated and delivered, and currently the public are less supportive of bioenergy than other renewable technologies (see **Box 9**). Researching the attitudes to energy crops among members of the public, the media, environmental lobbies, and politicians could identify reasons for the current lack of support, and ways of improving their acceptance.

8.5 Concluding remarks

There is clearly the potential in the UK to increase both PEC planting and woodland creation to the levels that are needed to deliver net zero GHG emissions by 2050. The conclusion from stakeholder interviews and output from the policy Delphi experts is that the barriers currently in place can be overcome **if** the Government makes significant and appropriate policy interventions. There is currently a perfect opportunity (or policy window) to implement the policies needed to support PEC planting and woodland creation. The replacement of the EU CAP with ELM and its focus on public money for public goods, and the new Environment and Agriculture Bills, provide opportunities for change. The strong public support for action on climate change, especially on tree planting, the pressure for a green economic recovery after the Covid-19 pandemic, and the COP26 conference to be held in Glasgow in November 2021 are all likely to put pressure on the Government to act.

Bioenergy has already suffered from a series of setbacks, from inconsistent policies and lack of support. Despite the key role of biomass in the CCC net zero scenarios, the future of energy crops is still uncertain. There is no influential energy crop lobby and public support is low. There is still a vociferous anti-bioenergy lobby and, although their main target is large-scale combustion of imported wood pellets, confidence in the rest of the bioenergy sector could suffer by association. The GHG benefits of BECCS using UK-grown PECs are easier to explain to politicians and the public than those for combusting wood, but successful delivery of BECCS will depend on government intervention to support both bioenergy and the development and deployment of large-scale CCS. Farmers will not plant large areas of PECs until financially attractive, guaranteed, long-term contracts are offered, but there is currently no indication that generators will receive the support that would enable such contracts to be offered. Government thinking may not be clear until the new UK Biomass Strategy is published in 2022, but the need to act is becoming more urgent as time passes, 2050 approaches, and the effects of climate change are being felt in the UK (CCC, 2021) and worldwide (IPCC, 2018).

There is currently strong support from the Government, the media, and the public for tree planting to sequester carbon, but it is important that the trees planted are species that can adapt to climate change, and that they are managed properly to achieve the sequestration required. Poor management or neglect can reduce sequestration and result in less useable timber. Large scale forestry needs the expertise of commercial foresters and the UK cannot rely on local community projects or wildlife charities to deliver the scale of planting needed to meet the target of net zero GHG emissions by 2050.

This research has highlighted that delivering new woodlands and large areas of PECs will face competition for land from food production, land restoration projects, and the expansion of settlements for an expanding population. The permanence of tree planting, and the high risk to farm incomes from permanent land use change, may mean that landowners will not plant trees and may instead opt for lower-risk PECs. As Jonathon Scurlock of the NFU argues in an interview with Gabatiss *(2020a);*

> *'They are far more likely to embrace climate beneficial measures, such as growing energy crops, or even planting isolated stands of trees, as long as there is the future possibility the land could be returned to other uses.'*

Incentives for the competing types of land use will have to be very carefully balanced if woodland and PEC targets are both to be met without impacting food production and without serious economic impacts on UK landowners. It could be easy to tip the balance in favour of one type of land use at the expense of other, equally desirable, uses. The effectiveness of policies will have to be constantly monitored and action will be needed (adjusting incentives, or providing additional support or advice) if they fail to deliver change. As time progresses, and the most suitable land is planted with PECs or woodland, it could become increasingly difficult to find new land for planting, and policies may need major reforms.

No matter how ambitious government plans are for tree planting or PEC cultivation, the decision to plant will most often be made by an individual landowner or a family, and these decision makers will ultimately determine whether the UK planting targets will be met. This research goes some way to showing how policy makers can bring these landowners on-board to deliver the land use changes needed as a part of the overall drive to reduce net UK GHG emissions to zero by 2050.

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Appendices

Appendix A: Stakeholder interview questions

Introduction

Introduction and thanks for agreeing to be interviewed.

Confirm who is present (the interviewee may have other people present for a phone call).

Consent

Can you confirm that you (all interviewees) have read the information sheet and consent form?

ave you any questions about the information sheet or consent form?

Are you happy for the interview to be recorded?

For a telephone interview verbal consent will be requested, using the consent form as a script. Or the interviewee may have emailed the consent form to me.

For a face to face interview, 2 forms will be provided for signature: one for me to keep and one for the interviewee.

Background information

Ask the interviewee to describe their role and prompt if necessary to elicit the following information:

What is the role of the interviewee: Landowner, farmer, farm manager, estate manager, consultant, sales rep, government employee etc.

Confirm the topics that are to be discussed (poultry litter, PEC, woodland creation, or management)

<u>Personal details</u>

Age or age range if they prefer: under 35, 35-44, 45 – 54, 55-64, 65 and over

Highest level of Education

Subject of degree/ diploma *

(* specifically whether the interviewee studied for a degree in an environmentally focussed subject or Agricultural/forestry)

Did this course include renewable energy (or forestry)?

Are you or your company members of any organisations which promote environmental activities/awareness or countryside stewardship?

Are you involved with any trade organisations or network?

Do you subscribe to any papers or journals?

Do you use consultants, advisors etc.?

Is the environment important to you and your organisation and is this an important factor in your business decisions?

For family businesses - is succession planning important to you?

Farm details

If this is a farm-based operation, please provide details of

- Farm type: Cereals, general cropping, horticulture, speciality pigs, poultry, grazing livestock (least favoured area?), grazing livestock (lowland), Dairy, mixed other (using the robust classification of farms). For arable, capture details of crops grown and rotation.
- If mixed or other please provide brief details
- Farm Size in Ha.
- Farm size in SLR (DEFRA standard labour requirement)

What sort of land is it – agricultural land rating (1 to 5), existing woodland etc.?

If this is not a farm, please provide details of the operation e.g. estate, council park, …

Are you the farm owner, manager, or tenant?

Have you been involved in any farm diversification projects – are any environmental?

Have you adopted any innovative practices on your farm?

Is the farm organic, or accredited with by a livestock welfare standard?

Do you generate any other renewable energy e.g. do you have:

- A wind turbine,
- A ground or air heat pump,
- solar panels (PV or thermal),
- hydro power,
- a biomass boiler – if so which type of fuel and who supplies it
- anything else?

Incentives and grants

Do you receive any incentives – FIT, RHI etc., or have you done so in the past, or are you planning to do so in the future.

Questions for Poultry Farmers

Operation details to gather

Species and type e.g. laying, broilers, breeders, pullets, hatchery?

Number of birds of each type and cycle length?

Annual tonnage of litter?

Current use of litter?

Price obtained for sale of litter £/tonne.

What is your current heat source for broilers, and do you claim RHI?

Any other potential heat demand locally – farm buildings, houses, other enterprises?

When did you become aware that that chicken litter can be used for AD, small scale combustion or large scale combustion?

Did you have a problem disposing of your poultry litter?

What did you do with it before you started to use AD/burning/selling to power station?

Before you got involved with using poultry litter in this way what did you think of this use?

What was the attitude of other poultry farmers to this use of litter?

Where did you get information about the uses of poultry litter?

- Part of previous of education
- Farming press
- From other farmers
- From suppliers/salesmen
- From Consultants
- From organisations such as NFU
- Other?

Did you use a consultant or developer when setting up your plant?

Did you see this technology being used successfully on neighbouring farms or farms elsewhere?

Were you able to trial it's use?

Were grants available to fund the AD or Boiler? (or were there any up-front cost for power station sales?).

Was finance easy to arrange. Could this be an issue for other farmers?

Were up front costs a barrier to adopting technology?

Were incentives easy to apply for?

Has this innovation proved to be successful/profitable?

Did you view this technology as a risky activity?

How compatible was it with your other farm practices?

Was it easy to implement/install/operate?

Was any specific training needed or are staff able to operate it easily etc?

Do you intent to carry on using this practice?

For power station contracts - how was the contract agreed – how long, mass, price?

Do you think that any of the problems you face are specific to your local area or do you think they are the same throughout the UK?

What changes to your industry do you anticipate in the future and will these changes affect your attitudes or practices?

Any other issues that you think are relevant?

Wrap up

Thank you for your help.

Mention what is happening next – I will use their data without disclosing their identity.

<u>Questions for Energy Crop farmers</u>

What experience do you have of Miscanthus, SRC (Willow or other) - harvesting, planting, machinery?

What experience do you have of annual energy crops (wheat, maize, beet…)?

When did you become aware of energy crops – annual and perennial as an option?

Did you have a particular reason for considering them – on farm demand for biomass, marginal land, reduction in labour requirement, environmental interest, incentive for planting energy crops...

What did you grow before that?

Before you got involved with energy crops -

What did you think of this use? Did you have any reservations?

What was the attitude of other farmers you know to energy crops?

Where did you get information about the innovation?

- Part of previous of education
- Farming press
- From other farmers
- From suppliers/salesmen
- From Consultants
- From organisations such as NFU

Other?

Did you use a consultant or developer or contractor when planting?

Did you see it being used successfully on neighbouring farms or farms elsewhere?

Were you able to trial it's use? On a small scale?

Were grants available to fund the planting at that time?

Was this a significant factor in planting?

Was finance needed? Was it easy to arrange? Could this be an issue for other farmers?

Were up front costs a barrier to adopting energy crops?

Did you have to buy new equipment for planting and harvesting or was this contracted out?

Were incentives easy to apply for?

Has this innovation proved to be profitable/ successful/manageable/ delivered all the expected benefits?

Did you view this technology as a **risky** activity?

How compatible was it with your other farm practices?

Was it easy to implement/install/operate?

Was any specific training needed/are staff able to operate it easily etc.?

Have you got contracts in place for the biomass? When and how were these agreed?

Have you got any opportunity for an integrated supply chain?

Do you harvest in winter? Have you considered earlier harvest for AD use?

Will you replant? If not, what will you plant instead?

Has there been any impact on drainage or land quality from growing the energy crops?

How has their experience been – as expected, better worse?

Do you think that any of the problems you face are specific to your local area or do you think they are the same throughout the UK?

What changes to your industry do you anticipate in the future and will these changes affect your attitudes or practices?

Any other issues that you think are relevant?

Wrap up

Thank you for your help.

Mention what is happening next - I will use their data without disclosing their identity.

Woodland questions

When did you first consider planting trees for fuel or changing your management of existing woodland?

Did you have a particular reason for considering planting trees or managing existing woodland:

- Wind break,
- Long term investment
- Reduce need for labour
- Environmental reasons
- Demand for wood fuel?

Was there an existing heat demand?

Were there environmental reasons?

What did you use the land for before woodland?

Before you got involved with this innovation -

What did you think of this use?

Is it compatible with being a farmer? Did you have any reservations about planting/managing woodland e.g. concerns about the long term impact on – landscape, perception of farm by others?

What was the attitude of other landowners you know to this planting?

Where did you get information about the innovation?

- Part of previous of education
- Farming press
- From other landowners
- From suppliers/salesmen
- From Consultants
- From organisations such as CLA or woodland trust
- Other?

Did you use a consultant or developer when planting?

Did you see planting/management used successfully on neighbouring land or elsewhere?

Were you able to trial it's use? On a small scale? What were the limits on size of planting?

Were/are grants available to fund the planting at that time?

Was this a significant factor in planting? Were grants easy to apply for?

Was finance needed? Was it easy to arrange? Could this be an issue for other landowners?

Were up-front costs a barrier to planting/managing woodland?

Did you have to buy new equipment for planting and harvesting or was this contracted out?

Has this innovation proved to be profitable/ successful/manageable delivered all the expected benefits?

Did you view this change as a **risky** activity?

How compatible was it with your other farm practices?

Was it easy to implement/install/operate?

Was any specific training needed / are staff able to operate easily etc.

How has your experience been – as expected, better worse?

Where does the biomass go – used within organisation or sold externally? Is a contract in place?

Are there any opportunities for an integrated supply chain?

Were you concerned about the impact on land values?

Do you think that any of the problems you face are specific to your local area or do you think they are the same throughout the UK?

What changes to your industry do you anticipate in the future and will these changes affect your attitudes or practices?

Any other issues that you think are relevant?

Wrap up

Thank you for your help. Mention what is happening next? – I will use their data without disclosing their identity.

Questions for power station operators/biomass users or dealers

How do you source poultry litter/miscanthus/SRC/wood?

What contracts are in place?

How far would they transport litter/biomass?

What are the plans for the power station in the long term?

Which types of biomass do you think have the most potential for use?

Are there any new types of biomass that they wish to support? If so, why?

Are you aware of any plans for more UK biomass power stations or do they think that the market is fully developed?

Are you facing any specific issues? Is there competing demand for biomass that is affecting the availability or the price?

Do you think that any of the problems you face are specific to your local area or do you think they are the same throughout the UK?

What changes to your industry do you anticipate in the future and will these changes affect your attitudes or practices?

Wrap up

Thank you for your help.

Questions for forestry or energy crop consultants

What services do you provide?

What Incentives and advice are currently available to farmers/landowners?

How easy is the process of claiming grants?

What pros, cons, barriers, and drivers do you think there are for adopting perennial energy crops / woodland planting or management for woodfuel.

Are there any specific issues with the perception of woodland/energy crops?

How do you disseminate information about new technologies? Are these the most effective ways?

What could be done to improve uptake?

Has the innovation(s) fulfilled expectations?

What sort of landowners/farmers are best suited to this type of activity?

Do you think that any of the problems you face are specific to your local area or do you think they are the same throughout the UK?

What changes to your industry do you anticipate in the future and will these changes affect your attitudes or practices?

Wrap up

Thank you for your help.

Appendix B: Land allocation calculations

The area of woodland planting in a region was calculated using Equations A.1 and A.2

$$Wr_{\,t} = WUK\left(Pw_t \cdot \frac{Lr_{\,t}}{LUK_{\,t}}\right) \qquad \text{Equation } A.1$$

Where Wr_t is the area of new woodland planting in a region on land of land type *t* where the land types are arable (*a*), temporary pasture (*tp*), permanent pasture (*pp*) and rough grazing (*rg*).

WUK is the total are of new woodland planting in the UK,

Pwt is the proportion of new woodland planting to be made on land of type *t* in the UK,

Lr_t is the current area of land in the region of type *t* and

LUK_t is the area of land in the UK of type *t*.

Wr, the total area of new woodland in a region is then the sum of plantings on all four types of land.

$$Wr = Wr_a + Wr_{tp} + Wr_{pp} + Wr_{rp} \qquad \text{Equation } A.2$$

In the same way the area of PEC planting in a region is calculated using equations A.3 and A.4

$$Er_{\,t} = EUK\left(Pe_{\,t} \cdot \frac{Lr_{\,t}}{LUK_{\,t}}\right) \qquad \text{Equation } A.3$$

Where Er_t is the area of new PEC planting in a region on land of land type *t*,

E_{UK} is the total are of PEC planting in the UK, and

Pe_t is the proportion of new PEC planting to be made on land of type *t* in the UK.

The total planting of new PECs in a region *Er* is then the sum of the plantings on all four types of land.

$$Er = Er_a + Er_{tp} + Er_{pp} + Er_{rp} \qquad \text{Equation } A.4$$

Appendix C: Policy Delphi information pack

Centre for Doctoral training in Bioenergy

SCHOOL OF CHEMICAL AND PROCESS ENGINEERING

UNIVERSITY OF LEEDS

Land-use change policy Delphi: data pack

June 2020

This document contains the following information for panel members taking part:

1. An outline of the Delphi process and guidance for answering the questions.
2. Details of the land use changes that could be required in England, and regionally in Yorkshire and Humberside, to contribute to UK net zero GHG emissions.
3. A list of the key barriers to woodland creation and energy crop cultivation in England.
4. A list of policies which have been suggested as appropriate for encouraging woodland creation or energy crop cultivation.
5. Information about the next step of the research.

Please read these sections before your telephone discussion.

There is also an additional data section for panel members who are interested in more background detail.

1. **Step one of the policy Delphi process**

A policy Delphi is a group communication exercise which involves a panel of experts taking part in an iterative process to gather information or attitudes in confidence. In a policy Delphi there is no need to reach consensus. The aim of this exercise is to assess the potential effectiveness of policies intended to facilitate the creation of new woodland and the cultivation of larger areas of miscanthus and willow for use in energy generation. I hope to identify potential complexity and possible policy interactions.

In this first round you will be asked a number of questions about your attitudes to land use changes and your opinion of individual woodland creation and energy crop policy instruments. I am interested in gathering your personal opinions, but if you feel that your employer has different priorities, I would like to collect these too. Most of the opinions will be assessed using standard scales shown in the table below. It may be useful to have these descriptions to hand during the discussion. For each question additional comments will also be sought, on the possible side effects of a policy and conflicts with other policies. If you feel that a topic or policy has not been included in the assessment, please provide details. If you don't want to answer or have no opinion on any question just let me know.

Table 1: Standard response descriptions

Attribute	Rating	Description
Desirability	Very desirable	Clearly beneficial.
	Desirable	Beneficial but may have minor negative effects.
	Undesirable	Will have some negative effects but may be justified overall in conjunction with other policies.
	Very undesirable	Extremely harmful or not justifiable.
Feasibility	Definitely feasible	Proven approach with no political or public objections likely.
	Possibly feasible	Possibly implementable, but not fully proven or some objections anticipated.
	Possibly infeasible	Some indications that it may be unworkable or unacceptable.
	Definitely infeasible	Unworkable or unacceptable politically or to public.
Effectiveness	Very effective	Very likely to deliver the desired effects.
	Effective	Likely to deliver some of the desired effects.
	Ineffective	Will have no effect either positive or negative.
	Counter productive	Likely to produce negative effects.

2. Land use scenarios

Many different organisations have modelled the land use changes that could be needed in the UK to deliver net zero greenhouse gas emissions by 2050. I have looked at three of these (the CCC *Further Ambition* and *Speculative* scenarios[1] and the ESC *Patchwork* scenario[2]) and calculated the impact that they could have on agricultural land use in Yorkshire and Humber (Y&H) and England as a whole. The key features of these three scenarios can be found below.

Table 2: Land use changes in UK by 2050 from three possible net zero scenarios

Scenario	New trees planted ha	Energy crops planted ha	Agroforestry
CCC further ambition	900,000	700,000	10 % of arable and 10 % of temporary and permanent pasture
CCC speculative	1,500,000	1,200,000	10 % of arable and 10 % of temporary and permanent pasture
ESC clockwork	900,000	1,400,000	

Using an Excel model, the land use changes resulting for the UK, England and Y&H from these scenarios were calculated using two different approaches to allocating the planting of energy crops and woodlands. These approaches are detailed in table 5 in the further data section: split one targets low quality land and split two uses more arable land. The model allocates planting of trees and energy crops across the UK depending on each region's share of the total UK land of each type. The areas of miscanthus, short rotation coppice (SRC) and short rotation forestry (SRF) are not calculated separately.

The results can be found in table 6. They suggest that England may need to plant up to 524,000 ha of woodlands, 690,000 ha of energy crops and convert up to 54,000 ha of arable land to silvoarable and 40,000 ha of pasture to silvopasture by 2050. These are ambitious targets requiring a significant increase in woodland planting over recent levels and a dramatic increase in energy crop planting in England.

3. Barriers to woodland creation and energy crop cultivation

My previous research aimed to understand the barriers that are preventing the planting of trees and perennial energy crops in Yorkshire and Humberside. I interviewed a range of stakeholders (including landowners, farmers and land mangers) who described the barriers they were aware of and made suggestions for the

[1] Committee on Climate Change. Land use: Policies for a Net Zero UK. 2020.
[2] Energy Systems Catapult. Innovating to net zero. 2020.

policies needed to overcome these barriers. The barriers identified are consistent with other research in the field.

The major barriers to landowners creating woodland included:

- The high initial planting costs of trees, guards and fencing.
- The loss of income from agriculture and long wait for income from wood.
- Loss of farm payment unless planted in a stewardship scheme.
- Higher incomes available from grant farming on upland farms.
- Woodland grants may be too restrictive on species and layout.
- Complex grants can scare off farmers who fear grant payments may be clawed back.
- Permanence of land use change.
- Fear of reduction in value of land when it is changed from agricultural to woodland.
- Hope of building on land.
- Cultural and attitudinal barriers resulting from separate farming and forestry industries.
- Importance to farmers of producing food.
- Reluctance to plant over the 'sweet spot' for tree planting of about 7% for a farm but higher for an estate.

The main barriers to farmers cultivating miscanthus and willow were found to be:

- There are few markets.
- Cereal crops are much more financially attractive.
- Perennial energy crops are not eligible for greening farm payments or stewardship schemes.
- No planting grants are available.
- Negative perceptions of energy crops persist (impact on soil, poor establishment, harvesting problems).
- Belief that farmers should grow food not energy crops.

4. Policies for promoting desired land use changes

As well as the suggestions from interviewees, many organisations have suggested policy changes needed to overcome these barriers. These include: The Woodland Trust[3], The Country Land and Business Owners Association (CLA)[4,5], The Energy Systems Catapult[6], The National Farmers Union[7], The Centre for Ecology and Hydrology[8], The Committee for Climate Change[9], The Forestry Commission[10], Crops For Energy[11], The Natural Capital Committee[12], The Soil Association[13] and CONFOR[14,15].

I have analysed the policies proposed by these sources and some of these polices are listed below. In our discussion I will be asking about your opinion of these policies: specifically I will be asking you to rate their desirability in an ideal world, their feasibility considering anticipated barriers to implementation and their potential effectiveness. I would also like you to describe any shortcomings or potential conflicts that you anticipate, and to propose additional policy options. Some of the policies suggested are already in use with varying levels of success.

The policy suggestions are listed overleaf in Table 3, grouped by the land use change that they are designed to promote: general polices, woodland creation policies (woods), agroforestry, and perennial energy crops (PECs) policies.

[3] The Woodland Trust. 2020. *Emergency Tree Plan for the UK.*
[4] CLA. 2018. *The land management contract.*
[5] CLA. 2009. *Forestry and Woodland Vision and Policy: Seeing the Wood for the Trees.*
[6] Energy Systems Catapult. 2020. Innovating To Net Zero.
[7] NFU. 2019. *Achieving NET ZERO: Farming's 2040 goal.*
[8] Whitaker, D.J. 2018. *A stakeholder workshop convened by the Centre for Ecology & Hydrology and the Committee on Climate Change.* Centre for Ecology and Hydrology.
[9] CCC. 2020. *Land use: Policies for a Net Zero UK.*
[10] Forestry Commission. 2019. *Forest Services Board Paper, 24 April 2019.*
[11] Lindegaard, K. 2013. *Why we need an energy crops scheme 3. Crops For Energy*
[12] NCC. 2020. *Natural Capital Committee: Advice on using nature based interventions to reach net zero greenhouse gas emissions by 2050.*
[13] Soil Association and Woodland Trust. 2018. Agroforestry in England: Benefits, Barriers & Opportunities. [Online]. Available from: https://www.soilassociation.org/media/15756/agroforestry-in-england_soilassociation_june18.pdf
[14] CONFOR. 2017. *A Common Countryside Policy Securing a prosperous green future after Brexit.*
[15] CONFOR. 2019. *The Future is Forestry: Tackling Climate Change With Trees.*

Table 3 Policy tools or changes proposed to deliver desired land use change

Number	Policy Area	Policy Proposal
1.	General	Develop a single integrated land use strategy and a single countryside and land-use policy covering farming, agriculture and ecosystems services delivery (balancing carbon sequestration with other priorities including food and timber production).
2.	General	Use public money to deliver public goods including evidenced based rewards for climate related activity.
3.	General	Payments for public goods should be more generous than current schemes and should include an element of profit for the land manager, rather than being based on average costs and income forgone.
4.	General	Remove any remaining tenancy constraints on change of land-use.
5.	General	Ensure that all carbon sequestration activity and public goods delivery (including woodland creation) is treated favourably in tax policy.
6.	Woods	Use a carbon market or trading scheme for land to attract private sector investment and increase the value of woodland creation.
7.	Woods	Allocation of land to trees should be a priority of a single land use strategy.
8.	Woods	Set national annual woodland planting targets.
9.	Woods	Local authorities must set annual planting targets and identify land for trees.
10.	Woods	Deliver government funded advice on woodland creation to landowners and farmers to help remove the divide between forestry and farming.
11.	Woods	Remove the division between forestry and farming in education.
12.	Woods	Provide long term policy certainty to enable scaling-up of the domestic forestry supply chain from nurseries to saw mills, rather than a series of 5 year policies.
13.	Woods	Woodland creation grants should provide adequate payments for establishment, pest protection and annual payments (to be competitive with other land uses).
14.	Woods	Provide public funding for woodland creation for non-carbon benefits e.g. for flood control, public access or biodiversity.
15.	Woods	Grant funding should increase with time as progressively better land is required for tree planting.
16.	Woods	Reduce the bureaucracy of woodland creation: streamline applications and approvals, increase the capacity of administrators, and make regulations simpler (Forestry act, Felling Licence regime, EIA requirements).
17.	Woods	Reduce the penalties incurred when planting schemes fail.
18.	Woods	New construction developments must include a minimum of 30% tree cover.

Number	Policy Area	Policy Proposal
19.	Woods	More forest partnerships like the Northumberland Forest should be formed.
20.	Woods	The importance of the commercial market must be recognised in all strategies and policies relating to the forestry and woodland sector.
21.	Woods	Improve the public perception of commercial forestry
22.	Woods	Allow planting of a wider range of species, including conifers and non-natives, to deliver resilience.
23.	Woods	Set targets for the use of UK timber.
24.	Woods	Remove subsidies for farming land that is more suited to forestry.
25.	Woods	Expand the UK nationally owned forests including working with public bodies with large land holdings.
26.	Woods	Remove the requirement to replant from terms of felling licences thus removing permanence of land use change.
27.	Agro-forestry	The government should provide a clear definition of agroforestry, and regulate it on equal terms with agriculture (i.e. remove penalties to adoption).
28.	Agro-forestry	The government should recognise the environmental benefits of agroforestry by including it in public goods environmental schemes.
29.	Agro-forestry	The government should support the trialling of agroforestry e.g. supporting advice networks and innovation networks.
30.	Agro-forestry	Develop a market mechanism to fund agroforestry (e.g. include it in woodland carbon trading).
31.	PECs	The government should signal their long term commitment to bioenergy.
32.	PECs	Use demand-side instruments to develop and strengthen the market for energy crops (e.g. carbon pricing support for bioenergy with carbon capture and storage) and continued support of biomass generation through existing measures (e.g. exclusion from emission trading scheme obligations).
33.	PECs	The government should provide backing for energy crop supply contracts.
34.	PECs	Oblige biomass combustion facilities to source a proportion of biomass from the UK with the proportion to rise over time.
35.	PECs	Establish an advisory service for energy crops to disseminate information to farmers.
36.	PECs	Provide planting subsidies/grants for establishment costs and to replace lost incomes during establishment.
37.	PECs	Include grants for establishing PECs in environmental schemes for delivering the public goods of biodiversity, nitrate and flood control.

Number	Policy Area	Policy Proposal
38.	PECs	Streamline cross-agency approvals of planting of PECs.
39.	PECs	Support energy crop research and development.
40.	PECs	Support private sector intermediaries who can raise awareness of financial benefits and arrange long-term contracts between farmers and end-users.
41.	PECs	Promote the benefits of PECs to the public and local communities.
42.	PECs	Provide grants to support the development of the full supply chain from planting materials through to harvesting and processing.
43.	PECs	Provide grants for removal of the crops at the end of their life.

5. Next steps

The data gathered from these calls will be used anonymously to update the policy option data which will then be reissued to all participants for further comments. A second call will then be arranged with each participant to gather feedback which will be used to update the policy data again. In a policy Delphi there is no need to reach a consensus: the aim of the exercise is to highlight potential policy outcomes and complexity.

Additional Data

In the calculation of land-use change in England and in Yorkshire and Humberside, woodland-creation and energy-crop planting were allocated to land types as specified in table 5, and then allocated pro rata across the UK depending on each region's share of the total UK land of each type. For example, if 80 % of tree planting is to be on rough pasture and Y&H has 2 % of the UK rough grazing then 1.6 % of UK tree planting will be on rough grazing in Y&H. The areas of remaining arable and pasture land were also calculated so that the area of agroforestry needed can be calculated. Rewilding and peatland restoration were not included in the model.

Table 5: Two approaches to allocation of planting between land types

Land use change	Land to be planted on used	Split 1: focus on lower quality land	Split 2: More planting on high quality land
Woodland planting	Arable	0 %	5 %
	Temporary pasture	5 %	15 %
	Permanent pasture	15 %	30 %
	Rough pasture	80 %	50 %
Energy crop planting	Arable	5 %	10 %
	Temporary pasture	10 %	20 %
	Permanent pasture	50 %	50 %
	Rough pasture	35%	20%
Agroforestry		10% of arable land, 10% of temporary and permanent pasture, no rough pasture	10% of arable land, 10% of temporary and permanent pasture, no rough pasture

Table 6: Land use change resulting from three selected scenarios and two approaches to allocation of planting

Scenario	land use change description	trees planted	ecrops planted	trees planted	ecrops planted	Silvoarable area	silvopastural area	new trees planted	new trees as % of agricultural land	additional energy crops planted area	ecrops as % of agricultural land	Silvoarable area	silvopastural area
		UK total	UK total	England	England	England	England	Y&H	Y&H	Y&H	Y&H	Y&H	Y&H
		ha	ha	ha	ha	ha	ha	ha		ha		ha	ha
CCC further ambition	Split 1: focus on low quality land	900,000	700,000	184,638	287,362			28,834	2.48%	36,781	3.17%		
CCC speculative	Split 1: focus on low quality land	1,500,000	1,200,000	307,729	492,621	406,198	336,857	48,057	4.14%	63,053	5.43%	53,501	39,842
ESC clockwork	Split 1: focus on low quality land	900,000	1,400,000	184,638	574,724			28,834	2.48%	73,562	6.34%		
CCC further ambition	Split 2: higher quality land	900,000	700,000	314,532	344,813			40,612	3.50%	41,486	3.57%		
CCC Speculative	Split 2: higher quality land	1,500,000	1,200,000	524,221	591,108	394,269	309,670	67,686	5.83%	71,119	6.13%	51,930	37,094
ESC clockwork	Split 2: higher quality land	900,000	1,400,000	314,532	689,626			40,612	3.50%	82,972	7.15%		

Appendix D: DECC assessment results in MW

Including data from AECOM (AECOM, 2011)

Electricity	Leeds				Leeds City Region				Yorkshire and Humber			
	AECOM potential	AECOM Actual	New potential	New actual	AECOM potential	AECOM Actual	New potential	New actual	AECOM potential	AECOM Actual	New potential	New actual
	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW
Co-firing with fossil fuels	0	0	0	0	413	0	4109	2,789	413	0	4109	2,789
Energy Crops medium scenario	6	x	2	0	62	x	28	8	185	x	80.6	13
Wood Fuel	x	x	x	0	x	x	x	0	x	x	x	0
Straw	1	0	1	0	16	7	13	9	93	78	37	41
WasteWood	3	x	x	0	10	x	x	0	17	x	x	32
Wet biomass (food and manure)	3	0	1	2	20	8	12	8	45	12	30	31
Poultry litter	0	0	0	0	6	0	7	0	35	14	30	0
MSW	2	0	4	11	15	25	18	107	28	80	32	129
Landfill Gas	x	8.6	x	9.2	x	40	x	41	0	83	x	66
Sewage	1	0	2	2	4	4	7	7	8	9	12	12
Total excluding co-firing	16	9	9	24	133	84	85	180	411	276	223	324

Heat	Leeds				Leeds City Region				Yorkshire and Humber			
	AECOM potential	AECOM Actual	New potential	New actual	AECOM potential	AECOM Actual	New potential	New actual	AECOM potential	AECOM Actual	New potential	New actual
Co-firing with fossil fuels	0		0	0			6163.5	0			6163.5	0
Energy Crops med	10	x	2	0	112	x	42	0	335	x	121	0
Wood Fuel	33	0	x	20	190	8	x	162	364	12	89	472
Straw	3	0	2	0	32	0	26	0	185	0	75	0
WasteWood	6	x	x	0	21	x	x	0	33	x	x	0
Wet biomass (food and manure)	3	x	1	8	23	x	24	18	52	x	61	77
Poultry litter	0	x	0	0	0	x	11	0	0	x	45	1
MSW	7	x	6	0	31	x	25	0	57	x	45	45
Landfill Gas	0	0	x	x	0	x	x	x	0	x	x	x
Sewage	0	0	3	x	0	x	10	x	0	x	18	x
Total excluding co-firing	62	0	14	28	409	8	137	180	1026	12	453	595

Appendix E: Calculations of biomass energy potentials

Miscanthus and Willow

	Uncropped area [1]	Additional area of miscanthus [2]	Current miscanthus cultivation [3]	Potential area of miscanthus	Mass of miscanthus per annum [4]
	ha	ha	ha	ha	odt
Leeds	549	362	37	399	5,992
LCR	10,332	6,819	616	7,435	111,520
Y&H	29,861	19,709	1,779	21,488	322,313

	Additional area of SRC [2]	Current SRC cultivation [3]	Potential area of SRC	Mass of SRC per annum [4]	total biomass
	ha	ha	ha	odt	odt
Leeds	181	13	194	1 941	7 933
LCR	3 410	208	3 618	36 176	147 696
Y&H	9 854	601	10 455	104 553	426 865

	Primary energy content [5]	Potential electricity per annum	Potential heat per annum
	TJ	GWh	GWh
Leeds	148	14	20
LCR	2,747	267	382
Y&H	7,940	772	1,103

[1] Uncropped land areas for local authority areas from DEFRA (2017d).

[2] Assume miscanthus on 67% of land and willow on 33% of uncropped land (SQW Energy, 2010).

[3] Current area of miscanthus and SRC from Table K of DEFRA (2017a).

[4] Miscanthus yield 15 odt ha^{-1} and SRC yield 10 odt ha^{-1} (SQW Energy, 2010).

[5] LHV of SRC (dry basis) 18.6 GJ t^{-1} (BEIS, 2017a) also used for miscanthus (SQW Energy, 2010).

Wood fuel

	Annual wood extractions for fuel [1]	Primary energy content of woodfuel	Potential heat per annum
	t	TJ	GWh
Leeds	3,520	52	12.2
LCR	26,400	388	91.6
Y&H	88,000	1,433	338.4

[1] Annual UK extractions for energy of 2 million tonnes (Forestry Commission, 2017a) apportioned to local authority areas by area of woodland cover (Forestry Commission, 2016a) (Y&H has 4.4 % of UK woodland, LCR has 1.3 % and Leeds 0.18 %).

[2] LHV of woodfuel 14.7 GJ t^{-1} (BEIS, 2017a).

Straw

	Total straw per year [1]	Straw available for energy [2]	Primary energy content of straw [3]	Potential electricity per annum	Potential heat per annum
	t	t	TJ	GWh	GWh
Leeds	31,818	4,773	64	6	9
LCR	515,786	77,368	1,036	100	144
Y&H	1,490,711	223,607	2,996	291	416

[1] Mass of wheat, barley and OSR straw produced based on areas of crops cultivated in the region in 2016 from DEFRA farm survey data (DEFRA, 2017d), and the yield of straw per hectare from Table 11 of DEFRA (2017a).

[2] Assume 15 % of straw is available for energy after competing demands (AHDB, 2018c).

[3] LHV of straw of 13.4 GJ t^{-1} (BEIS, 2017a).

Waste Wood

	Construction and demolition waste [1]	Sawmill waste [2]	Total waste wood available for energy [3]	Primary energy content of waste wood [4]	Potential electricity per annum	Potential heat per annum
	t	t	t	TJ	GWh	GWh
Leeds	48,545		24,273	461	45	64
LCR	117,351		58,676	1,115	108	155
Y&H	200,600	18,969	109,785	2,086	203	290

[1] Construction and demolition waste for Y&H (Pöyry Forest Industry Consulting Ltd and Oxford Economics Ltd, 2009) apportioned to local authorities by proportion of construction completions (MHCLG, 2012).

[2] Sawmill waste for Y&H (Forestry Commission, 2016b).

[3] Assume that 50 % of waste wood is available for energy (SQW Energy, 2010).

[4] Using LHV of waste wood of 19.0 GJ t^{-1} (BEIS, 2017a).

Manure

	Mass of pig and cow manure [1]	Annual methane production [2]	Energy content of gas [3]	Potential electricity per annum	Potential heat per annum
	t	thousand m^3	TJ	GWh	GWh
Leeds	143,420	2,868	63	6	9
LCR	2,668,288	53,366	1,174	114	163
Y&H	6,845,560	136,911	3,012	301	418

[1] Animal numbers from DEFRA farm survey 2016 (DEFRA, 2017d). Per annum each cow produces 12.2 t and each pig 1.33 t of manure (SQW Energy, 2010). Assuming 80 % of manure can be collected and 100 % can be used for energy (SQW Energy, 2010).

[2] Methane yield of pig and cow manure 20 m^3 t^{-1} (NNFCC, 2017b).

[3] Energy content of methane 22 MJ m^{-1} (Banks, 2009).

Maize

	Area of maize cultivated [1]	Maize available for energy [2}	Annual methane production [3]	Energy content of gas [4]	Potential electricity per annum	Potential heat per annum
	ha	t_{DM}	thousand m^3	TJ	GWh	GWh
Leeds	275	1,262	414	9	1	1
LCR	2,413	11,076	3,633	80	8	11
Y&H	8,477	38,909	12,762	281	28	39

[1] Area of maize cultivated from DEFRA farm survey 2016 (DEFRA, 2017d).

[2] Assume maize yield of 17 t DM ha^{-1} (AHDB, 2018a), 27 % of maize will be available for energy as in 2016 from Table A of DEFRA (2017a).

[3] Methane potential of maize 328 $m^3\, t_{DM}^{-1}$ (Murphy et al., 2011).

[4] Energy content of methane 22 MJ m^{-3} (Banks, 2009).

Poultry Litter

	Total poultry excreta (broiler, turkey and laying hens) [1]	Primary energy content [2]	Potential heat per annum [3]
	t	TJ	GWh
Leeds	2,832	22	5
LCR	76,821	584	138
Y&H	328,086	2,493	589

[1] Total of bird numbers from Defra 2016 farm structure data for county/unitary authority (DEFRA, 2017d) and excreta rates from DEFRA (2015b) Table 32. Assume all litter can be collected and there is no competing demand SQENERGY

[2] Using LHV of 7.6 GJ t^{-1} (BEIS, 2017a).

[3] Assess poultry litter as a source of heat only with boiler efficiency of 80 %.

MSW

	Total Annual Waste collected [1]	Waste not recycled [2]	Biogenic waste available for energy [3]	Energy content of MSW [4]	Potential electricity per annum	Potential heat per annum
	t	t	t	TJ	GWh	GWh
Leeds	338,209	84,552	43,967	298	29	42
LCR	1,376,988	344,247	179,008	1,217	118	169
Y&H	2,494,152	623,538	324,240	2,204	214	306

[1] From local authority collected waste, DEFRA (2018b) Table 1, data for 2016/17 financial year.

[2] Assumption that 25 % of MSW will not be recycled: the target set in the Waste Strategy for England (DEFRA, 2007).

[3] Proportion of residual waste collected which is biogenic is 52 % from Table 2 of DEFRA (2014).

[4] LHV of MSW 6.8 GJ t^{-1} (BEIS, 2017a) table A.1.

Landfill gas

Area	Installed capacity [1]	Assumed load factor [2]	Annual electrical generation	Annual electrical power generation [3]	Primary Energy [3]
	MW		GWh	GWh	TJ
Leeds	13.8	0.504	61	87	628
LCR	39.9	0.504	176	251	1,811
Y&H	92.3	0.504	408	581	4,191

[1] Installed capacity from Renewables and CHP register (OFGEM, 2018b).

[2] Load factor from table 6.5 of BEIS (2017a).

[3] Assume potential associated heat at a ratio of 1.4 units of heat per unit of electricity.

Sewage Sludge

	population [1]	Sludge per annum [2]	Methane per annum [3]	Energy content of gas [4]	Potential electricity per annum	Potential heat per annum
		t_{DM}	m^3	TJ	GWh	GWh
Leeds	751,000	17,498	8,749,150	192	19	27
LCR	3,048,500	71,030	35,515,025	781	76	109
Y&H	5,425,700	126,419	63,209,405	1,391	135	193

[1] Population from ONS (2012) Table KS105EW.

[2] Annual sludge production per person in the UK of 23.3 kg dry matter (Bianchini et al., 2016) and assume all is available for anaerobic digestion.

[3] Methane potential of sewage sludge 500 $m^3\ t_{DM}^{-1}$ (Biomass Energy Europe, 2010).

[4] Energy content of methane 22 MJ m^{-3} (Banks, 2009).

Appendix F: Data used for biomass potential and actual use assessments

	Value	Reference	
General			
Load factor for landfill	52.5 %	BEIS (2016, p. 189)	Table 6.5
Load factor for EFW	39.6 %	BEIS (2016, p. 189)	Table 6.5
Load factor for AD	62.2 %	BEIS (2016, p. 189)	Table 6.5
Load factor for plant biomass	87.2 %	BEIS (2016, p. 189)	Table 6.5
Minscanthus and SRC			
Use of Miscanthus and SRC for bioenergy		OFGEM (2018a)	
Woodfuel			
RHI accredited installations (domestic)		BEIS (2018d)	Table 2.11
RHI accredited installations (non-domestic)		BEIS (2018d)	Table 1.4
Average capacity of RHI accredited installations		BEIS (2018d)	Table 2.12
Load factor for all wood fuelled domestic installations		BEIS (2018d)	pp. 75–76
% of RHI supported installations by technology type		BEIS (2018d)	Table 1.4
Load factor for all wood fuelled non-domestic installations		BEIS (2018d)	Table 1.8
Straw			
Biomass sustainability report 2016-2017		OFGEM (2018a)	
Waste wood			
Biomass sustainability report 2016-2017		OFGEM (2018a)	

AD	
Commercial AD plant output	Renewable Energy Foundation (n.d)
Farm AD plant capacities	NNFCC (2017b)
MSW	
EFW plants	Tolvik Consulting (2016)
EFW plant capacities	Individual company websites
Landfill	
Landfill schemes earning ROCs	OFGEM (2018b).
Sewage Gas	
Sewage gas schemes earning ROCs	(OFGEM, 2018b)

Appendix G: NVivo codebook node structure for interview themes

Themes from Rogers' DOI are underlined.

Node name	New Node?	Interviewees	References
Agroforestry	✓	2	4
Attitude to replanting perennial energy crops		4	5
Attitude to the environment	✓	17	21
Barriers			
Energy crop barriers		10	39
Absence of consistent UK energy policy		2	6
Delayed income from energy crops		1	1
Disapproves of energy crops	✓	1	1
Farm payment scheme	✓	1	1
High initial cost of planting energy crops		3	4
Lack of a market for energy crops		2	4
Lack of confidence following ARBRE project		2	5
Need for special machinery for energy crops		1	1
Not recognised as sustainable crop	✓	2	2
Other crops give better income than energy crops		1	1
Waste regulations	✓	2	4
Poultry litter as energy barriers		9	71
Ammonia	✓	1	4
Biosecurity	✓	3	4
Contractors take the litter away	✓	1	2
Current heating system is working well with no need for change	✓	2	3
Demand for fertiliser		6	12
Distance from power station	✓	1	1
Few technology suppliers	✓	1	1
Initial cost of technology	✓	4	6
Litter type, volumes, and logistics	✓	1	3
Maintain existing disposal route	✓	1	2
No AD plant near by	✓	2	2
No demand for heat on farm		1	1
Price of litter has increased	✓	2	2
Regulations on burning on farms	✓	4	10
RHI insufficient	✓	1	2
RHI is already claimed for wood fuelled boiler		3	7
Scale	✓	4	7

Node name	New Node?	Interviewees	References
Woodland planting or management barriers		14	31
Access	✓	4	4
Environmental impact assessment needed for woodland creation		1	1
Farm subsidies or single farm payment CAP	✓	11	20
Farmers hold negative attitudes to wood planting		4	7
Farmers hope to build on land	✓	1	1
Feeling that land should be used for growing food not fuel		2	2
Forestry Commission change of role	✓	2	4
Government policy	✓	3	6
Grant system		3	8
High initial investment		8	12
Lack of awareness of benefits of tree planting		4	4
Lack of confidence in the market for woodfuel		3	6
Lack of information about tree planting		2	2
Lack of knowledge		7	14
Land is held by tenants		7	14
Land value reduction	✓	10	13
Long period for investment to pay back		4	5
Loss of income or opportunity cost	✓	4	5
New skills		2	2
Permanent change to land use categorisation		3	8
Permission to plant trees, planning	✓	1	3
Public liability for trees		1	1
Split between forestry and agriculture	✓	3	7
The public have negative view of tree planting	✓	3	3
Uncertainty over funding of upland planting		1	1
Wood management barriers	✓	6	10
Biomass use		1	1
Contracts for biomass sales		7	19
Integrated supply chain		2	2
Uses of wood extracted	✓	11	28
Brexit	✓	4	6
<u>Communication channels</u>		29	88
Advisors	✓	15	21
<u>Friends and neighbours</u>		3	4
<u>Homophilous actors</u>		9	13
<u>Information in the media</u>		14	17

Node name	New Node?	Interviewees	References
Opinion leaders		1	1
Sales reps		3	3
Trade organisations		17	20
Discontinuance		6	10
Drivers		34	340
Drivers for energy crops		12	47
Contracts available	✓	4	9
Demand on-farm for biomass		1	1
Feedstock for AD		3	6
Fits well with rotation	✓	2	4
Low maintenance crop		2	4
Market for biomass present	✓	2	2
Financially attractive crop	✓	5	6
Reducing GHG emissions and reliance on fossil fuels		0	0
Suitable for poor quality, marginal or expensive to farm land		5	11
Suitable for type of farmland	✓	1	1
Drivers for using poultry litter		8	31
50 % limit on energy crops in AD	✓	1	1
AD plant on-farm or nearby		2	5
Difficulty in disposing of litter		3	5
Good feedstock	✓	1	3
Need for heat and reduce energy costs		2	2
NVZ restrictions		5	5
RHI for litter		3	5
Solving litter storage problems	✓	1	1
Drivers for woodland planting or management		25	243
Aesthetics or amenity	✓	11	18
Air quality		1	1
Carbon budgets and offsetting	✓	6	11
Climate change	✓	3	3
CSR opportunities		1	1
Demand for fuel or timber		14	21
Economically advantageous	✓	3	3
Environmental reasons for tree planting		12	19
Future income stream - retirement fund		3	3
Grants and incentives		20	48
Increased value of wood	✓	7	21

Node name	New Node?	Interviewees	References
Investment regeneration etc.	✓	1	2
Low effort farming	✓	2	2
New skills needed for woodland	✓	3	3
Replacing trees lost in storms	✓	1	2
Restoring woodland	✓	2	6
Shelter belts		6	6
Shooting	✓	4	5
Tax benefits particularly inheritance tax		6	7
The Northern Forest	✓	9	24
Unproductive areas	✓	6	7
Water quality and flood management		9	13
Woodland management drivers	✓	11	18
Environmental impact assessment EIA	✓	1	1
Environmental impact of innovation	✓	3	5
<u>Experience of adoption</u>		15	86
<u>Experience of innovation - economic viability</u>		5	7
<u>Experience of innovation - expected benefits realised</u>		6	10
<u>Innovation - impact on land quality</u>		5	6
<u>Innovation - impact on land value</u>		1	3
<u>Unexpected benefits following innovation</u>		2	3
Farm or woodland practices		24	86
Countryside stewardship	✓	13	19
Farm energy and diversification projects		19	45
Forest standards		2	2
<u>Innovative Farm practices</u>		8	11
<u>Member of environmental organisation</u>		4	4
Funding tree planting	✓	1	1
Future intentions or fears		22	40
Incentives for energy crops or energy use		11	18
<u>Normative belief - what others expect of interviewee</u>		3	4
<u>Perception of innovation</u>		21	87
<u>1 Relative advantage</u>		10	21
<u>2 Compatibility with other practices</u>		9	22
<u>3 Perceived complexity</u>		5	5
<u>4 Trialability</u>		5	5
<u>5 Observability of new innovation</u>		12	14
<u>6 Risk of innovation adoption</u>		5	5
Pests - squirrels deer voles etc.	✓	9	24
Public goods		4	7

Node name	New Node?	Interviewees	References
Regional or local factors	✓	23	32
SSSI, national park, protected landscape etc.	✓	5	6
Steps in decision making		16	27
1 Knowledge - becoming aware of the innovation		15	22
2 Forming an opinion of innovation - persuasion		3	5
3 Making decision		0	0
4 Implementation of decision		0	0
5 Confirmation of decision		0	0
Tree diseases	✓	1	3
Tree species native v conifer	✓	12	17
Urban trees	✓	3	4
Woodland cover - optimum, target etc.	✓	4	4
Woodland for amenity, recreation, or conservation - non timber reasons	✓	5	6
Woodland management	✓	6	16