On-Farm Anaerobic Digestion Uptake Barriers and Required Incentives: A case study of the UK East Midlands region

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Abstract

In the UK, on-farm anaerobic digestion (AD) can deliver renewable energy, improved management of farm wastes and the production of fertiliser, offering cost-savings, environmental improvements and potentially revenue generation, yet on-farm uptake of AD remains very limited. The research reported here provides an in-depth exploration, in the UK's East Midlands region, of the factors behind this limited uptake. We also analyze factors that will help to increase uptake. Data collection has been undertaken in three stages – a

questionnaire sent to farmers, 18 interviews with stakeholders from the industry and policy sides of the AD debate, and a stakeholder workshop. The barriers identified were grouped into political & institutional, AD awareness, and economic & technical. Key policy recommendations include the creation of a single body to act as a focal point for on-farm AD-related information-gathering and dissemination, streamlined planning processes, improved access to finance, and stable policies that recognise both the renewable energy and waste management benefits of on-farm AD.

Keywords: Anaerobic Digestion, Renewable Energy, United Kingdom, Uptake Barriers, Waste Management

Highlights:

- AD offers waste management and renewable energy generation outcomes
- On-farm uptake of anaerobic digestion in the UK is low
- Multiple barriers to uptake are found in an analysis of the UK East Midlands region
- Key barriers are financial, information, planning and policy stability-related
- Coherent, holistic responses to all barriers are required to boost uptake

1. Introduction

The United Kingdom (UK) is at the forefront of efforts to tackle climate change and promote renewable energy (RE) transitions. It committed, in the 2008 Climate Change Act, to reduce its greenhouse gas (GHG) emissions by 35% below 1990 levels by 2020, and 80% by 2050, (DECC, 2012).[1] This domestic commitment exceeded its international obligations: a 20% reduction committed to via the 2009 European Union (EU) Renewable Energy Directive (RED); the 2018 revised RED (RED II), with renewable energy targets for 2030; and the Kyoto Protocol.[2] By 2017, UK GHG emissions were already 43% below 1990 levels (Committee on Climate Change, 2018).[3]

Under the RED, the UK committed to delivering a 15% share of renewable energy in gross final energy consumption by 2020 (see BEIS, 2019a, for the UK position on targets through to 2030, related to RED II).[4] By 2017, the UK had achieved 10.2% (BEIS, 2018b). Energy

[1] In 2018, a decade after it was passed, the 2008 Act received a positive review even from the campaign group Friends of the Earth (Friends of the Earth, 2018).

[2] We do not analyze the possible implications of Brexit in this paper. Our focus is the domestic UK renewable energy transition – and the UKs domestic commitments are considerable. Assuming no backsliding on domestic commitments, we expect Brexit to have little or no consequence for our research questions.

[3] In 2019 the UK revised its 2050 target, becoming the first major economy to enshrine in law a 100% reduction (i.e. a net zero emission) target (BEIS, 2019b). In 2019 also, the UK went for two weeks without coal power for the first time since the Industrial Revolution (Embury-Dennis, 2019).

[4] RED II does not set out national targets but, having set an EU-wide target of 32% of energy coming from renewable sources by 2030, requires member states to determine their own contributions to this through their Integrated National Energy and Climate Plans (NECPs). Brexit notwithstanding, the UK commits in its Draft NECP to maintain its commitment to climate change-related efforts.

generation data (BEIS, 2018a) show that renewables had about a 24% share of the total in 2017. Within that, roughly 50% of electricity generation came from renewable sources, but the contributions of different RE sources vary considerably. According the data from BEIS (2018a), by 2017, RE generation was dominated by wind (50%), solar photovoltaics (12%) and bioenergy (32%), with bioenergy dominated by plant biomass (20% of total RE).

Of the RE technologies available, we focus on anaerobic digestion (AD), specifically on-farm AD. AD 'is the process by which organic matter such as animal or food waste is broken down to produce biogas and biofertilizer. This process happens in the absence of oxygen in a sealed…tank' (BIOGEN, 2018). This technology has been used to treat sewage sludge for over 100 years (DECC/DEFRA, 2011, p. 5), but its use as a source of RE remains modest. In 2017, AD contributed 8% of UK bioenergy generation, just 2.5% of total RE.

This limited deployment is significant because, in addition to its use for treating sewage sludge (Gregson et al., 2015), AD can generate electricity via the disposal of wastes (Bywater, 2011); offering farmers a new source of income (Massaro et al., 2015). Waste management is particularly significant for agriculture, where pollution incidents from animal wastes are a major problem. The Environment Agency (2018, p. 13) reports that agriculture is in the top 3 of regulatory sectors for pollution incidents – and the only one showing an increase in incidents in 2017-18, of 13%. AD is an established technology that can be used to generate RE via the management of highly polluting on-farm wastes. It creates for farmers income-generating and cost-reducing opportunities which can make AD economically sustainable whilst enhancing the environmental sustainability of energy generation and agricultural production in the circular economy. Given the range of positive benefits available from AD, the present study seeks to understand the reasons that may lie behind the limited on-farm

deployment (see also Röder, 2016), considering also questions around the future governance and policy options for sustainability.

On-farm AD has received some attention in the existing literatures on RE, AD and waste management, but these studies have tended to focus on a very narrow range of issues. Several studies focus on the technical aspects of AD, including Achinas et al. (2017), who analyze the technical opportunities of generating biogas from lignocellulosic wastes; Komilis et al. (2017), who analyze the literature on methane yields from AD systems which utilize food wastes; Lijó et al. (2017), who analyze the emissions and environmental impacts of different feedstock combinations and digestate production; and Yang et al. (2017), who explore how the AD process can be manipulated in order to produce more methane. We build on a much smaller body of literature, which takes a qualitative social science perspective, in two important ways. First, most of the contributions to this literature, detailed in Section 2, adopt a single method of data collection in their research design. In contrast, we take a mixed methods approach to primary data collection, utilizing a large-N survey, small-N interviews and a workshop (as detailed later). This permits a *deeper* exploration of the factors that might affect the uptake of on-farm AD. Second, most studies have a focus that is very narrowly defined ex ante, in terms of the issues with on-farm AD that they concern themselves with.[5] Rather than pre-define our specific research focus, we ask research questions that allow us to explore the full *breadth* of the multiple challenges facing the increased uptake of on-farm

[5] As discussed further below, Tranter et al. (2011) are only interested in the energy-generating potential of on-farm AD; Tidy et al. (2015) studied just six farms that had adopted AD; and Röder (2016) focused on the possible land-use implications from growing energy crops for AD.

AD. These innovations represent the key methodological and empirical research gaps that we address.

In keeping with the limited literature, we focus on one UK region: the East Midlands region of England. Given the importance of AD as a potential solution to waste management as well as RE generation, this region represents the median in terms of English regions' shares of livestock and pig numbers (albeit with a higher than median share of poultry – data for all English regions are presented in Appendix Table 1). It therefore represents an important illustrative case study in the UK context of potential AD utilization.

From the foregoing and to give focus to our analysis, we identify three research questions:

1. What barriers affect on-farm AD uptake in the East Midlands?
2. What incentives and support mechanisms are required to increase the number of on-farm AD projects in the East Midlands?
3. What are the perceptions of stakeholders in the East Midlands of current UK policy measures, planning and regulatory regimes around on-farm AD?

In Section 2, we review key relevant literature. Section 3 provides details of our research design and methods of data collection. Section 4 presents the detailed analysis and discussion of our survey and interview data. Section 5 concludes the paper with a summary of the key implications from our findings and suggested directions for future research.

2. Literature Review

Research on AD is located within a number of overlapping literatures, including general studies on AD, broader studies of on-farm RE, and general studies on RE. Several studies look at different countries, or undertake a cross-country comparison. In what follows we focus on studies looking at on-farm AD in the UK, except insofar as other studies offer particular insights relevant to our research questions.

2.1. Anaerobic Digestion – a review of the general *UK literature*

We first review the literature which analyzes on-farm AD via theoretical *ex ante* modelling. As a source of RE and as a waste management system, AD 'represents key opportunities for the UK bioenergy sector.' (Welfle et al., 2014, p. 261). These authors utilize a Biomass Resource Model, with feedstock inputs and technology pathways in their model including farm wastes and AD. Modelling approaches have also been adopted to understand the *potential* for on-farm AD in the UK (notably Gowreesunker and Tassou, 2016). These papers are an important part of the AD debate, as they identify technical-economic opportunities for AD – and, as Jones and Salter (2013, p. 216) point out, are required to fill in for the limited 'normative empirical data', resulting from the limited uptake of AD on UK farms (the gap that we seek to address).

Findings notable in the context of the present study are, from Jones and Salter (2013), that AD can be profitable on medium-large arable farms only when energy crops are grown for the AD unit (an issue we return to later; see also Röder, 2016). That said, AD is not equally well suited to all farm types, nor farm sizes, and its profitability varies with price and subsidy levels. AD is an excellent way of treating slurry (Bywater, 2011), making it particularly suitable for

dairy farms (Banks et al., 2011). The digestate – the by-product of the AD process – can be used as a fertilizer, but the availability of land for this can limit the scale of the AD unit (see also Bywater, 2011).

As a way of reducing energy costs, Gowreesunker and Tassou (2016) find that AD is cost-effective for all farms modelled. Looking at two different types of end-use – combined heat and power (CHP) and heat only – they find that the relative competitiveness of one or the other depends on the levels of feed-in tariffs (FiTs), Renewable Obligation Certificates (ROCs) and the Renewable Heat Incentive (RHI). Pig farms are more likely to adopt CHP units than other farm-types, given the former's higher ratio of electricity use to heat use. Although the details of the models and the magnitudes of the estimates differ, the findings of these modelling-based studies are broadly consistent, adding collective robustness to their individual conclusions (see also Zglobisz et al., 2010, who study AD generally, not just on-farm).

A second body of literature consists of papers that focus on policy questions. Bywater (2011, p. 35) makes the straightforward but nonetheless important observation, that '[i]ncentives should be at such a level as to make AD at least as attractive as simply putting up a slurry storage tank'. These findings are complemented and reinforced by studies analyzing markets and policies in other countries, for example Wilkinson (2011) in Australia and Germany; Edwards et al. (2015) in Australia, Denmark, Germany, the UK and the US; and Bangalore et al. (2016) in Austria, Denmark, Germany, the Netherlands and the US. All three studies find that FiTs have a significant positive impact on AD uptake. Edwards et al. (2015), who look at both on-farm and industrial AD, find policies that divert food wastes from landfill, and include waste performance incentives, have a positive impact on AD uptake. Gregson et al. (2015),

drawing on an analysis of secondary materials, identify the positive waste-management properties of AD in the context of the circular economy debate.

2.2. Anaerobic Digestion – primary research into on-farm adoption in the UK

A third, much more limited, literature on AD, draws on primary (quantitative and/or qualitative) data collection and analysis. This is the literature to which we contribute. The three key studies in this literature all utilize different methods of data collection: Tranter et al., 2011 (large-N questionnaire data); Tidy et al., 2015 (small-N comparative case study); and Röder, 2016 (interviews, site visits and observation). Each also has a different specific focus. Tranter et al. (2011) seek to establish the energy-generating potential from on-farm AD (farmers across England were surveyed); Tidy et al. (2015) study six farms with AD already adopted (in the South West region of England); and Röder (2016) focuses on the possible land-use implications from growing energy crops for AD (on farms in the East of England region). Our mixed methods approach complements and extends these considerably, as discussed in Section 3.

Common features are present across these three studies. AD needing to deliver an adequate 'return' or 'profit' is dominant. The generation of RE is recognized as relevant, although Röder (2016) finds evidence that this is seen as a benefit more than a driver. Waste management is also seen as an important factor. These studies find similar barriers, including set-up costs, planning processes, an uncertain and unstable policy environment affecting returns, lack of information about AD and availability of feedstocks for AD units. We note here an interesting parallel with research into AD as a means of treating wastewater. In a literature also dominated by technical considerations, studies which consider barriers to uptake find a strikingly similar set of challenges to uptake. These include costs of infrastructure and

required equipment; lack of effectiveness of funding schemes; lack of effectiveness of investment incentives; regulations at the local and national levels; community objections and suitable market infrastructure (Jones and Lemar, 2015; Pfluger et al., 2019).

A final issue to report is the growing of 'energy crops' (notably maize) specifically for use as a feedstock in AD units, the primary focus of Röder (2016). In contrast to the intense debates around land-use and land-use change in the context of growing feedstocks for biofuels (Ackrill and Kay, 2014), the issue is seen quite differently in the context of AD. Tidy et al. (2015, p. 274), when identifying possible ways of boosting AD uptake, include increasing FiTs…'to recognise energy crop costs'. Röder (2016, p. 79) finds that stakeholders are sanguine about using farmland to produce energy crops:

> *'Farmers also argued that land has always been used for non-food crops, e.g. for animal feed, malting or other industries. For them land use or even food-fuel conflict as such does not exist as different crops have different functions within the agricultural system and land use is therefore multifunctional. The interviewed farmers raised also concerns that the amount of food wasted along the supply chain is a much bigger land user than energy crops.'*

That said, this position is questioned by the academic literature (Lijó et al., 2017) and approached with concern in UK policy documents (DECC/DEFRA, 2011).

Building on this very limited literature, we focus on a region of the UK that we argue is typical, rather than exceptional, in the present context (Tidy et al., 2015, for example, focus on a region of the UK where dairy production is dominant). Our research questions and research design take inspiration from the factors identified above from other studies, but ours is the first to seek an in-depth and unified understanding of the potentially multiple barriers that are holding back on-farm AD. Tranter et al. (2011), writing some years ago, focused on the

Commented [AR1]: This rewrite is based on my dissatisfaction, in hindsight, with the previous version. I think the changes make for a smoother journey through this passage.

potential for on-farm AD; our intention now is to try to understand why on-farm AD uptake *remains* modest, despite that potential.

3. Research Design and Methods of Data Collection

We adopt a three-stage mixed methods research design, to obtain the necessary range of information from relevant stakeholders to be able to offer answers to our research questions. This approach to obtaining complementary information from different stakeholders via multiple methods, distinguishes this paper from most of the literature. As dictated by our research questions, we obtain some numerical data, but mostly we seek discursive, qualitative, data.

First, we adopted a survey design and distributed a questionnaire to farmers in the East Midlands region. This provided information important in answering the first two research questions. Second, we interviewed 18 stakeholders, obtaining information that would help to answer all three research questions. Third, we hosted a Roundtable Workshop where a range of stakeholders were able to discuss our preliminary findings with us – and with each other. This enabled us to validate further our research findings and helped us to answer all three research questions.

For our survey, we developed a questionnaire instrument (see the online Appendix) that combined open and closed questions, generating primarily qualitative responses. With the support of the regional National Farmers Union (NFU) office, we sent questionnaires to the 1586 farmers in the counties of Derbyshire and Nottinghamshire in the East Midlands registered as NFU members, in March 2016 (we acknowledge that this may led to a slightly biased sample, as not all farmers will be members of the NFU). 153 usable questionnaires were received back, a response rate of 10% (lower than Tranter et al., 2011, but comparable to Maye et al., 2009, cited by Tranter et al.). Responses were evenly distributed between farmers in Nottinghamshire and Derbyshire, 78-75 respectively. A profile of respondent characteristics is provided in Appendix Tables 2 and 3, and Appendix Figure 1.

In the second stage of data collection, we conducted 18 in-depth interviews with stakeholders: farmers, AD installers, AD operating directors, an NFU representative, a representative of the Anaerobic Digestion and Bioresources Association (ADBA), and officers from the UK Environment Agency (see also Appendix Table 4). To ensure consistency, all interviews were conducted by one researcher. They were all audio recorded and then transcribed by the researchers. Where necessary, follow-up contact was made to clarify particular responses. The interviews were semi-structured, guided by the project research questions, the academic literature and a preliminary analysis of the survey data.

The third stage of the data collection consisted of a workshop of AD stakeholders, held at Nottingham Trent University in January 2017. Participants represented the farming and AD industries, local authorities and academia.

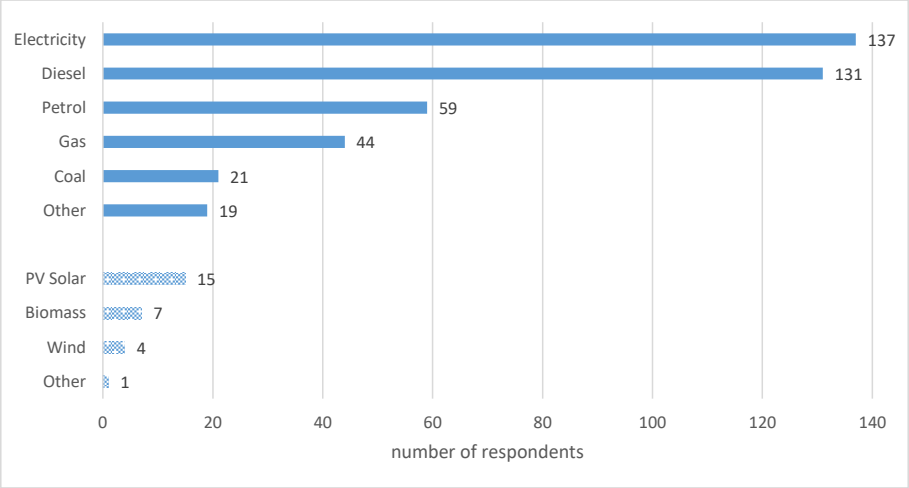
4. Results and Discussion

Our research design and research questions focus on a qualitative understanding of key issues around on-farm AD uptake. In this section, we start with an overview of findings based (mainly) on the closed questions on the questionnaire. We then undertake a content analysis of responses to the open questions on the questionnaire, and the interview data, triangulated against the discussion at the workshop and, as appropriate, the academic literature.

4.1. Renewable Energy Demand and Supply

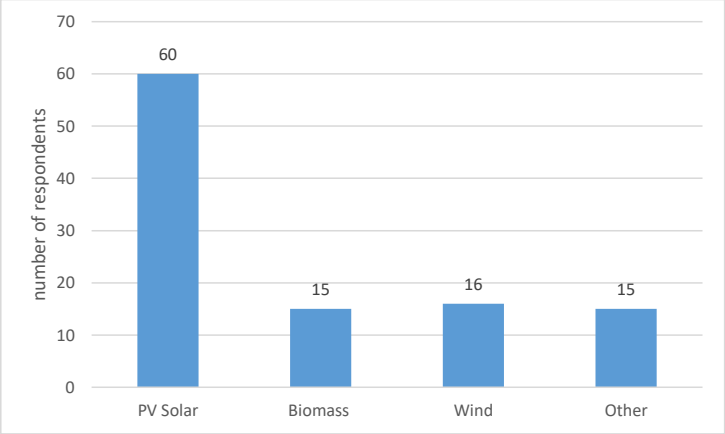
Figures 1 and 2 provide an overview of farmers' engagement with energy markets in general, and renewable energies in particular, as consumers and producers. In Figure 1, 'electricity' refers to all off-farm purchases, whilst the lower set of bars indicates only those farmers who are aware that they are buying energy generated from renewable sources.

Figure 1: Off-Farm Purchases of Non-Renewable and Renewable Energy



Note: 148 separate respondents declared purchases of non-renewable energy and 23 declared purchases of RE.

Figure 2: On-Farm Generation of Renewable Energy



Notes: 85 separate respondents declared on-farm generation of RE, but with several producing more than one type of RE the total number of observations is 106. Not all farmers gave precise details of RE feedstocks and

technologies, but from the information provided 'Biomass' consisted mainly of wood and woodchips. 'Other' consisted, primarily, of heat pumps (both ground and air source).

Within our sample, only one respondent had an AD plant, whilst two respondents supplied feedstock to AD plants. Of the 85 farmers represented in Figure 2, 35 sold RE off-farm 'regularly', with a further 11 doing so 'occasionally'. We found no significant correlation between farm-type and on-farm RE generation and only weak correlation between on-farm RE generation and farm turnover. A strong correlation was found between farm type and off-farm purchases of RE.

4.2. Thematic Analysis of the Coded Qualitative Data

To analyze the extensive data generated by the interviews and open questions on the questionnaire, we undertook content analysis based on a two-stage coding process, utilizing NVivo software. First, we identified deductively a series of *a priori* codes based on our research questions. These were mainly manifest codes; terms we expected to see referred to by participants. In a few cases, we also included latent codes; terms that we would not expect participants to use, but would be implicit in what they said. In Table 1, most of these concepts are manifest codes, but 'multilevel governance' is an extremely important latent code. Second, as we read through the qualitative responses, we looked for additional emergent codes that could be added inductively. 'Grid connectivity' falls into this category. From this, three sets of barriers were identified, each divided into multiple sub-themes. We follow Table

1 in structuring the analysis below. Before the detailed thematic analysis, we first offer a few observations about participants' general views on AD.

Table 1: Analytical Themes of Barriers to on-farm AD in the East Midlands

Main Themes	Sub-Themes
Institutional and Political Barriers	Planning and regulatory complications
	Multi-level governance (MLG) complications
	Opposition of local communities
	Stability of regulations and regulatory measures
Awareness of AD	Awareness of AD technologies and regulations
	Awareness of UK government's RE incentive measures
Economic and Technical Barriers	Supply of feedstock to on-farm AD
	Grid connectivity
	Availability of finance
	Type and size of farms and farming business

Our interviewees believe that AD in general, and on-farm AD in particular, has an important role to play in achieving the UK's RE targets(a view found also by Röder, 2016), its limited uptake notwithstanding. Interviewees highlighted two key differences between AD on the one hand, and wind and solar on the other – that AD has the potential to operate continually, day and night, without interruption for seasonal or climatic factors, with its energy products

having the potential to be stored and used when needed, to help balance the supply-demand equation.

Compared with wind and solar, our interviewees highlighted that AD offers an important carbon-neutral role in the circular-economy, as a means of waste-management and disposal (Gregson et al., 2015). Benefiting the farm balance-sheet, AD generates by-products that can be used as fertilizer. This can be substituted for purchased fertilizer, saving on input costs and, should excess fertilizer be sold to other farmers, offers an additional income stream. Interviewees were careful to point out the strengths of AD as being highly context-specific, making its potential scale and contribution to the UK's RE mix more limited than wind and solar. This is an important finding, given the linkages between AD as a source of RE generation and as a means of on-farm waste management.

For AD to be part of the circular economy, it has to be the right waste. One finding from the questionnaire was that the single most important reason for the non-adoption of AD, given by 56% of respondents, was that it was not compatible with their farming activities. The significance of this triangulation is that whilst many interviewees, from across the full range of stakeholders, saw the benefits of AD, it was the farmers who highlighted this simple but critically important barrier to AD adoption: the mix of activities on the 'UK farm' limits potential AD adoption.

4.2.1. Institutional and Political Barriers

Interviews revealed multiple concerns related to *planning and regulatory complications*, compounded by the *multilevel governance* setting of policy. The process was seen as being

emotional and subjective, made worse by a general lack of support for AD. These are likely to be linked to the view that local planning authorities lack full understanding of what AD is and how it functions. Concern was also expressed about the time the planning process can take. Locally, farmers operating in the Peak District National Park in Derbyshire face particularly tough planning regulations. There was agreement that planning regulations were required – but that they needed to be eased in the context of on-farm AD. These concerns expressed by several interviewees were reflected also in the responses of the farmers surveyed. 43% of questionnaire respondents cited planning issues as a reason for non-adoption. They feared loss of money and time in what may well be an unsuccessful drawn-out application.

In a multilevel governance context, the interaction of local and national regulation created complications and concerns. One interviewee highlighted one cause of complication as being a lack of communication between the many governmental agencies involved in granting planning permission for AD plants. 12% of questionnaire respondents cited overly-burdensome regulations as a distinct disincentive to adopting AD.

One reason for the existence of such complicated governance structures is the multifunctional nature of AD, as both an energy source and as a means of waste disposal. This makes AD licencing subject to the interaction of numerous authorities and subject to public consultations, both statutory and non-statutory. Several years ago the argument was made that '[t]here should be a single and definitive point of information for regulations surrounding anaerobic digestion, as there are clearly some grey areas and conflicting advices from different bodies' (Bywater, 2011, p. 36). Our participants showed the continued lack of such a body is an ongoing barrier to adoption.

An issue highlighted by a number of interviewees concerned the *opposition of local communities* to the location of AD units on local farms, something also likely to feed into planning debates. Interviewees highlighted a range of arguments brought to bear by local communities, notably concern over an increase in transport bringing feedstock to AD plants, worries over odours, and opposition to energy crops being used in AD units. Interviewees also noted that 'not in my back yard' and 'anti-stuff' groups were always there 'to object for the sake of objection'. One interviewee (CONS1 in Appendix Table 4) is a farmer-owner and a local councillor, bringing insights from different sides of this debate. He argued that, before starting a planning application to install an AD unit on-farm, farmers should make sure that the community is well aware of it and is already on their side.

A third set of codes and themes analyzed under institutional and political barriers is the *(in)stability of regulations and regulatory measures*. Several interviewees spoke about this and its negative impact on AD adoption. This was also identified as a barrier by 22% of questionnaire respondents. To quote interviewee ADOP1b:

> *It changes a lot, and it's difficult to understand. That's true. It's definitely very difficult to understand. We've been to two different courses, and the lecturers specifically said it is very complex. You need to interpret and understand it, and yet it might change again.*

This argument relates to the overall regulatory environment, but also to the calibration of individual policy instruments (Kay and Ackrill, 2010). Notably, continual changes to FiT rates were a real concern to farmers, as they create an unstable investment environment, with uncertainty around the long-term economic viability of AD investments. This highlights both

the critical importance of financial incentives to AD viability and uptake, and the concomitant need for stability and certainty.

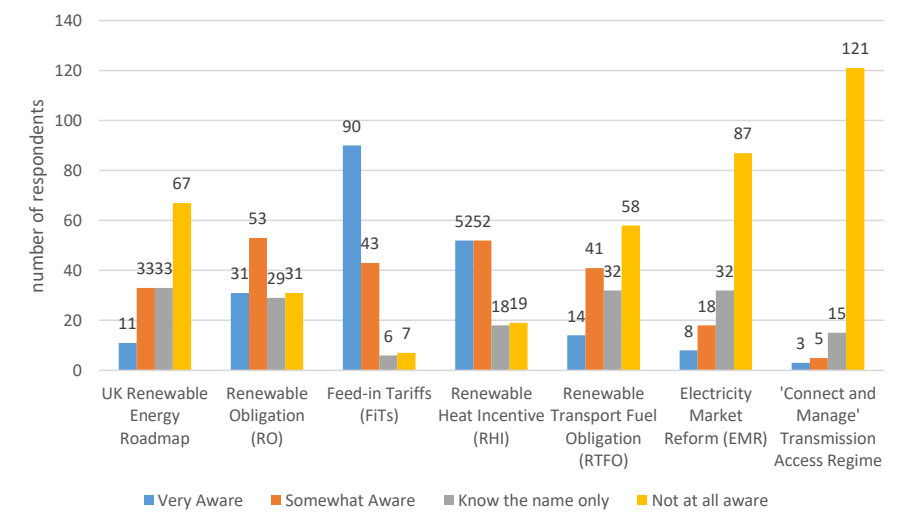
4.2.2. Awareness of AD

Our coding distinguished between two dimensions of awareness – technologies and regulations; and UK government policy incentives. Considering first *awareness of AD technologies and regulations*, one interviewee argued that AD can be an integral part of the farming business, so farmers should know about it (see also Röder, 2016). Another suggested that information about the possible on-farm energy mix refers typically only to wind and solar. Underpinning the concerns raised by both of these interviewees is the absence of a clear mechanism to spread awareness about AD as an important RE source. Again, these interview findings aligned with questionnaire findings, with 21% of respondents identifying a lack of information about AD technology as a barrier to their adoption.

Both the interviews and the open-ended questions on the questionnaire allowed participants to identify specific areas where a lack of awareness created barriers to adoption: awareness of regulations around AD investment; finance required and finance sources; costs, revenues and payback periods; AD unit scale and feedstock options; the usefulness and appropriateness of the digestate; the skills required to operate an AD unit; and the fuel required to run an AD unit. These findings reflect earlier studies (such as Bywater, 2011; Tranter et al., 2011; Duruiheoma et al., 2014), which confirms a lack of progress in providing information essential to the development of on-farm AD adoption.

With *awareness of UK government RE incentives and measures*, UK RE policy includes a number of instruments, such as FiTs, the RHI and ROCs, to encourage investment in different RE technologies. Figure 3 summarizes questionnaire responses exploring participants' awareness of different UK RE policies and instruments. A wide range of awareness-levels across different policies and instruments was found. No significant relationship was found between farmers' education levels and their awareness of AD. These survey findings were confirmed by detailed responses from interviewees. A specific policy-related gap in understanding concerned AD-related taxes and subsidies. As a result, a broad range of awareness-raising activities is required.

Figure 3: Awareness of UK Government RE Policy Measures and Instruments



4.2.3. Economic and Technical Barriers

Our third set of themes/codes concerns economic and technical barriers, with four specific types of barrier identified and analyzed. We begin with the *supply of feedstock to on-farm AD*. AD has the potential advantage over wind and solar RE that it can operate continually, but only with a steady supply of feedstock for the digester. Several interviewees, especially farmers, were concerned that this might not be the case. Livestock farms are often seen as being well-placed to take advantage of AD, but our interviews revealed a concern that whilst AD feedstocks such as slurry and manure might be available during the winter months, if animals are kept indoors, when put out to grass in the summer months the supply of these feedstocks would be harder to maintain. Importing feedstock from other farms could be a problem, with concerns raised by interviewees including more heavy-duty vehicle traffic in farming areas. Such as increase in traffic could also increase emissions, reducing the net environmental benefits of AD. Regulations on the inter-farm movement of animal-based feedstocks may also restrict supply for AD.

One option might be to supplement the supply of farm wastes to AD by the growing of crops such as maize and ryegrass as AD feedstocks. Analysis of our interview and survey data exposed a strong split in views; a split reflected also in earlier studies, suggesting that they are deeply rooted and hard to reconcile. Several participants made the point that farmers have always used land for non-food purposes (see also Röder, 2016). One interviewee observed that using land to grow energy crops is low risk in terms of a shift of agricultural practice and food security in the UK (see also Röder, 2016). The integration of energy crops grown for AD on non-cultivated areas has positive returns in terms of both energy generation and GHG emissions (Boscaro et al., 2018), but Tranter et al. (2011) raise concerns over food

security. The benefit of AD as a means of waste management implies a presumption of not growing energy crops on any scale.

A second potential economic and technical barrier to AD uptake is *grid connectivity*; highlighted by both interview and survey participants. Several argued that the (in)ability to sell AD-generated energy could be a barrier to AD uptake. Related barriers included the distance of the farm from the grid connection point and the high cost of connecting AD units to the grid. A technical limitation two interviewees identified was that the age and capacity of the UK national grid do not provide adequate capacity and accessibility to absorb the supply of RE. A lack of connectivity is not a barrier for farmers who intend to use AD-generated energy as a substitute for off-farm purchased energy (not all of which depends on grid connectivity). It is a barrier for those farmers whose *economic* decision to adopt AD includes the ability to sell the energy generated into the national grid.

A third barrier is *availability of finance*. 29% of questionnaire respondents identified lack of access to finance as a barrier to AD adoption. Interviewees argued that, given the potentially high cost of establishing an AD unit (see also Tranter et al., 2011), the lack of a reliable source of financing is a significant barrier to AD adoption. Interviewees suggested that the government should be a source of loan finance for AD adoption, but recognised that government approval for loans could be time-consuming. They saw a link between this as a reliable source of finance and the policy unpredictability caused by changing goals and objectives. One workshop participant (a manager at an urban AD plant) spoke with passion about the barrier to AD uptake that lack of access to finance represented.

The fourth theme identified as an economic and technical barrier is the *type, size of farm and farming business*. Interviewees made the point that the cost of adopting AD was more

manageable on larger and more profitable farms. Several questionnaire respondents stated that being a tenant was a barrier to AD adoption. As one farmer put it, 'as a tenant, AD involves a high amount of investment in someone else's property'. We found a statistically significant correlation between the type of farm ownership and non-adoption of AD from our questionnaire data.

4.3. Incentives Required for AD Uptake

Given the many barriers to AD adoption, and the extremely low level of adoption amongst our survey sample, we explored with our interviewees the incentives they would require to adopt AD technologies on their farms. Given the sampling procedure adopted, we only interviewed farmers for whom AD was at least a potential option for them.

Two factors were prominent from these interviews: access to finance and risk reduction. Specific suggestions for improved incentives included the provision of grants, the provision of tax incentives, and support from government to enable banks to lend for AD investments. Greater stability of policies and policy instruments would help to encourage adoption, delivering also a reduction in the perceived risks around AD investments. Several interviewees identified the potential gains from positive demonstration effects: farmers would be attracted to AD if they saw that it could help them to make money and/or reduce their waste management costs.

Third, our interviewees argued for help to bring farmers together, to work and support each other in order to benefit collectively from AD units (Tranter et al., 2011; Duruiheoma et al., 2014). One possible option might be collaboration over an off-farm AD unit. This would raise

traffic concerns, but could avoid falling foul of regulations over the movement of farm wastes *onto* other farms. A final point arising from our interviews, and one relevant to addressing a number of the barriers to AD adoption identified in Section 4.2, is to make available smaller AD units. These would be lower-cost, require less feedstock, and could offer off-grid farmers a way to manage their waste and reduce the energy they bought-in (Bywater, 2011). It would also reduce the amount of digestate produced, the on-farm spreading of which is limited by land availability. If there were seasonal fluctuations in the supply of manure and slurry for reasons set out above, supply could be stabilized, potentially, by the limited utilization of non-farm food wastes.

4.4. Required Changes to Planning and Regulation

Several interviewees referred to planning and regulation as an area where changes would be of great benefit. With *planning*, several argued for a simplification of the planning process – especially in the context of providing flexibility, where AD adoption is part of a farmer's day-to-day business. Interviewees also called for a single agency to be able to grant planning permission. One interviewee suggested that the government should contribute to the costs of making a planning application, helping to make farmers feel more secure and supported in their efforts at RE generation. Regarding the current *regulatory regime*, several interviewees called for farmers to be able to take local food waste as AD feedstock. Farmers should be given more freedom to move feedstocks between farms, to ensure a sufficient supply, year-round. Creating a single agency to oversee AD would help address the complexity of the planning process. It would enable these complex issues to be discussed in a more coherent way than is possible at present.

4.5. Review and Discussion of Key Findings

The foregoing, detailed, analysis of interview and qualitative questionnaire data identifies numerous barriers to the adoption of on-farm AD. This research complements the extensive literature that explores technical dimensions to the adoption of on-farm AD. It also now extends the much more limited, and more narrowly-focused, qualitative research on the limited uptake of on-farm AD. The holistic approach to research design and analysis in the present paper reflects the complex and overlapping economic, political and social contexts within which on-farm AD must operate. In reflecting on the main lessons that can be drawn from the foregoing analysis, we do not offer a hierarchy of barriers and responses. Rather, we argue that the barriers identified represent a set of problems that must be addressed holistically. Without an integrated approach to the promotion of AD, partial efforts may represent second-best solutions (Lipsey and Lancaster, 1956) which raise the risk of total failure (c.f. Tidy et al., 2015, pp. 273-274).

We find that most barriers occur at the stage of deciding whether to invest in AD. These include a subset of barriers that are foreseen as potentially arising after adoption. Chronologically-speaking, the first barrier is awareness of AD. Many farmers felt inadequately informed about AD as a technology. Policy ambiguity in a multilevel governance setting itself makes it harder for farmers to become better-informed. Even where farmers and other stakeholders were aware of AD, potential adoption was undermined by their awareness of policy instability and uncertainty. Feedstock options were not well-understood. Where farmers were better informed about feedstock options, they had concerns over maintaining an adequate supply of feedstock to operate the AD unit.

Our initial approach to this research was to understand AD as a means of waste-to-energy RE generation. As the questionnaire results and interview data were analyzed it became clear that, in order to avoid truncating our analysis, we should look at all AD feedstock options. A very small number of participants argued that farming has always undertaken activities other than growing food for humans or feed for animals (c.f. Tidy et al., 2015; Röder, 2016). Two survey participants confirmed they grow energy crops specifically to sell for AD. The much more widely-held view amongst our participants (as reflected also in the limited literature) is that farmers should not be encouraged by policy incentives to grow crops for AD. The question of growing energy crops as feedstock for AD remains persistent. The dominant view from our participants was that this should not be promoted by policy. However, farmers should not be stopped from supplying crops for AD units as part of the business activity, just not be given fiscal incentives to do it. Making the receipt of FiTs conditional on respecting sustainability criteria for feedstocks used in the generation of RE is an important step forwards (Ofgem, 2017).[6] As with sustainability criteria for biofuels (Ackrill and Kay, 2014), this will help to limit emissions arising from possible land use change effects.

If farmers reach the point of deciding to invest in an on-farm AD unit, the next set of barriers to overcome is to get permission for it. This is a significant potential barrier, consisting of the inter-linked challenges of gaining the support (or at least avoiding the opposition) of local communities, and gaining the support of the planning authorities. One possible problem is that, just as farmers feel uninformed about AD, so too can locals and planners. Presenting AD as a tool for on-farm waste management could tackle concerns over smell. A comparison with slurry tanks offers the opportunity to highlight AD as reducing smell and the potential

[6] See, in particular, Table 1, pages 11-12.

environmental damage from waste leaking into water courses, for example. Nor would the utilization of on-farm waste generate additional road-traffic. The comment from interviewee CONS1, about working with locals to garner support ahead of any planning application, identifies an approach that would allow for such site-specific factors to be addressed. Reforms to the entire planning process for on-farm AD need to be considered.

If farmers are able to get planning permission other, forward-looking, concerns may prevent them from adopting AD. Even if policy signals and fiscal incentives are supportive of AD adoption now, uncertainty over future FiT levels may make future economic viability sufficiently uncertain for farmers not to invest (c.f. Tranter et al., 2011). Even if an AD unit is intended purely for generating energy for on-farm use, uncertainty over interest rates can limit the number of farmers investing in AD (c.f. Tidy et al., 2015). One possible policy response to address these concerns is Contracts for Difference, which could be used to stabilize AD revenues (see UK Government, 2017).

5. Conclusions

By exploring the barriers to AD adoption in the UK, through an in-depth qualitative investigation in the UK's East Midlands region, we have determined the breadth of barriers to on-farm adoption. We have triangulated our findings internally, across questionnaire responses, interviews and a workshop; and externally with reference to the (very limited) literature. Some differences in concerns emerged across stakeholder types – notably farmers

being more concerned about the year-round supply of liquid farm wastes (slurry and manure) than other stakeholders – but most of the concerns were evident and shared across stakeholders and participants.

Our analysis offers a series of proposed changes to improve AD adoption. Given the need for a holistic approach to tackling multidimensional challenges, we repeat the call of Bywater (2011, p. 36), that 'There should be a single and definitive point of information for regulations surrounding anaerobic digestion'. A possible model for this exists in the Waste and Resources Action Programme (see WRAP, 2019). Despite WRAP's existing activities around on-farm AD, the limited uptake indicates that a step-change is required in promotion efforts, through more coordinated policy leadership. This would address the challenges arising from the current complex, multilevel governance structure, offer a central source of information for all stakeholders (including planners and local communities) and provide a critically important focal point for discussions around the financing of AD, seen as one of the most significant barriers to AD uptake.

Critical for AD adoption is economic viability, itself conditional on a regular supply of feedstocks. Participants in our research argued for a review of legislation controlling the movement of farm and food wastes, believing that it is overly restrictive. The use of energy crops grown specifically for use in AD units was not generally opposed in principle, but there was considerable opposition to having policy incentives encouraging this.

The findings from this study offer several directions for further research. There is scope for in-depth research around tackling each of the barriers identified. For example, why are banks reluctant to lend to farmers to purchase on-farm AD, and how can policy help? What might the transport implications be of enabling greater use of off-farm wastes? How might planning

processes be adapted to facilitate greater on-farm AD adoption? One limitation of the present study is the lack of participants who have adopted AD already. To develop this aspect (and go beyond the small-N sample in Tidy et al., 2015), there needs to be a greater understanding of how adopters have been able to take up on-farm AD.

Finally, whilst we have argued that this study focuses on a UK region that is fairly typical in terms of the farming activities most relevant for AD, there remains considerable scope, first, for corroborating these findings elsewhere in the UK; and, second, for undertaking cross-country comparative studies. With the latter, especially looking at countries like Germany with its much greater AD adoption, deeper understanding can be obtained of both how to increase AD uptake ;and the potential downsides of expanding AD uptake when it is based on policies promoting the growing of energy crops, rather than promoting the utilisation of AD as part of a farm's waste-management system.

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What follows below is intended to be published as an Online Appendix.

We include it here as a single document to aid the reviewing process.

Online Appendix

Appendix Table 1: Percentage Shares of Animal Numbers by English Region, June 2016

Region	Cattle	Pigs	Poultry
North East	5	3	2
North West	18	4	7
Yorkshire/Humber	10	38	12
East Midlands	**9**	**10**	**21**
West Midlands	13	5	15
East of England	4	25	22
South East	8	5	8
South West	33	10	14

Source: DEFRA, 2018.

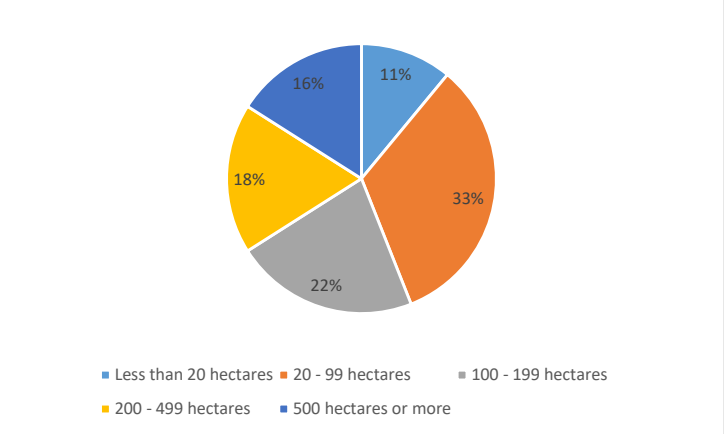
Appendix Table 2: Profile of Questionnaire Respondents

Descriptive Statistics		Number	%
Farm Location	Nottinghamshire	78	51
	Derbyshire	75	49
Farmer Gender	Male	141	92
	Female	12	8
Age of Farmer	Less than 30	4	3
	30-39	8	5
	40-49	27	18
	50-59	52	34
	60-64	24	16
	65 and over	37	24
	Prefer not to say	1	0
Highest Formal Academic Qualification	None	30	20
	GCSE	20	13
	NVQ	14	9
	A Levels	9	6
	University Degree	42	28
	Masters	4	3
	Doctorate	2	1
	Other	44	30
Type of Farm	Arable	56	37
	Livestock	51	33
	Mixed	46	30
Farm Ownership	Owned by you	88	57
	Shared ownership	29	19
	Rented	16	10
	Other	20	13
Annual Farm Turnover	Less than £10,000	8	5
	£10,000 - £19,999	6	4
	£20,000 - £29,999	4	3
	£30,000 - 49,999	8	5
	£50,000 - £74,999	9	6
	£75,000 - 99,999	10	7
	£100,000 - £149,999	14	9
	£150,000 - £199,999	11	7
	£200,000 and over	61	40
	Prefer not to answer	22	14

Appendix Table 3: Distribution of Animal-Based Farms in the Questionnaire Sample

Number of:	0	1-9	10-19	20 - 29	30 - 49	50 - 99	100 +	N
Dairy Cows	4	1	0	0	0	6	21	32
Cattle, non-dairy	0	7	4	10	8	14	21	64
Sheep	2	1	2	1	3	6	25	40
Pig	4	3	1	0	0	0	5	13
	0	**1- 999**	**1,000-49,999**		**50,000 - 99,999**		**Over 100,000**	**N**
Chickens	3	16	4		2		0	25

Appendix Figure 1: Size Distribution of Arable Farms in the Questionnaire Sample



Note: 115 farmers responded to this question. This exceeds the number of farmers who self-identified as having arable or mixed farms (56 and 46, respectively).

Appendix Table 4: Interview Details

Interview Date	Interviewee's profession	Code	Years of Experience	Interview duration	Mode of Interview
02-Aug-16	NFU – Trade association	NFU1	4 years in NFU – 30 Years as a farmer	33 minutes	Face-to-face
03-Aug-16	Farmer - Owner	FARM1	40 years	46 minutes	Face-to-face
05-Aug-16	Farmer - Partner	FARM2	13 years	40 minutes	Face-to-face
08-Aug-16	Farmer - Partner	FARM3a FARM3b	42 years	27 minutes	Face-to-face
09-Aug-16	Farmer - Partner	FARM4	45 years	26 minutes	Face-to-face
11-Aug-16	Farmer - Partner	FARM5	60 years	34 minutes	Face-to-face
11-Aug-16	AD Installer – Managing Director	ADOP1a ADOP1b	20 years	47 minutes	Face-to-face
12-Aug-16	Farmer - Partner	FARM6	60 years	27 minutes	Face-to-face
15-Aug-16	Farmer - Owner	FARM7	30 years	22 minutes	Face-to-face
16-Aug-16	Farmer - Owner	FARM8	35 years	40 minutes	Face-to-face
17-Aug-16	Farmer - Owner	FARM9	36 years	34 minutes	Face-to-face
18-Aug-16	ADBA – Policy Officer	ADBA1	5 years	52 minutes	Face-to-face
22-Aug-16	Farmer - Owner	FARM10	50 years	47 minutes	Face-to-face
22-Aug-16	AD Plant Director	ADOP2	10 years	49 minutes	Face-to-face
02-Sep-16	AD Plant Marketing Director	ADOP3	10 years	36 minutes	Telephone

08-Sep-16	AD Industrial Regulator – Environmental Agency	GOV1	20 years	65 minutes	Face-to-face
19-Sep-16	Senior Advisor for the Waste Industry – Environmental Agency	GOV2	12 years	26 minutes	Telephone
23-Nov-16	Farmer – Owner and Councillor	CONS1	27 years	34 minutes	Face-to-face

Questionnaire

Part 1 – Questions about you and your farm

Q1 What is your age?

- Less than 30 years old
- 30 – 39 years old
- 40 - 49 years old
- 50 - 59 years old
- 60 – 64 years old
- 65 years old and above
- Would prefer not to say

Q2 What is your gender?

- Male
- Female
- Would prefer not to say

Q3 What is your highest formal qualification?

- No Qualifications
- GCSE
- NVQ
- A Level
- University Degree
- Masters
- Doctorate
- Other (Please specify)……

Q4 What type of farm do you have (please provide brief details in the space below)?

- Arable
- Livestock

- Mixed

……
……

Q5 What is the location of your farm?

- Nottinghamshire
- Derbyshire

Q6 Farm Ownership: is your farm:

- Owned by you
- Shared ownership
- Rented
- Other (Please specify)…….

Q7 What is your role in the farm?

- Sole Owner
- Partner
- Manager
- Other (Please specify)…….

Q8a If you have arable land, what area does this cover?

- Less than 20 hectares
- 20-99 hectares
- 100-199 hectares
- 200-499 hectares
- 500 hectares or more

Q8b If you have livestock, what number of animals do you have in the following categories?

	Dairy Cows	Cattle, non-dairy	Sheep	Pigs	Chickens	
1-9	☐	☐	☐	☐	1-999	☐
10-19	☐	☐	☐	☐	1000-49999	☐
20-29	☐	☐	☐	☐	50000-99999	☐
30-49	☐	☐	☐	☐	100000 +	☐
50-99	☐	☐	☐	☐		
100 +	☐	☐	☐	☐		

Q9 What is the approximate annual turnover of your farming business?

- ☐ Less than £10,000
- ☐ £10,000 - £19,999
- ☐ 20,000 - £29,999
- ☐ £30,000 - £49,999
- ☐ £50,000 - £74,999
- ☐ £75,000- £99,999
- ☐ £100,000 - £149,999
- ☐ £150,000 – 199,999
- ☐ £200,000 and over
- ☐ Prefer not to answer

Part 2 – Some Information about the Sources of the Energy You Use

Q10a What off-farm sources of non-renewable energy do you purchase for use on your farm?

- ☐ Coal
- ☐ Gas
- ☐ Electricity
- ☐ Diesel
- ☐ Petrol
- ☐ Other (Please specify)……..

Q10b What off-farm sources of renewable energy do you purchase for use on your farm?

- ☐ PV Solar
- ☐ Wind
- ☐ Biomass (Please specify feedstocks, if known)……..

Q11 What on-farm sources of energy do you generate?

- ☐ Biomass (please specify feedstocks)……..
- ☐ PV Solar
- ☐ Wind
- ☐ Other (Please specify)……

Q12 Do you sell any energy you have generated, off-farm?

- ☐ Regularly
- ☐ Occasionally
- ☐ No
- ☐ If you do, approximately what percentage of energy generated is sold off-farm?.....

Part 3 – Some General Questions Relating to Anaerobic Digestion (AD)

Q13 Which of these do you believe to be the main reason(s) that governments have policies which seek to promote AD? Please tick all that apply:

- Renewable energy promotion
- Waste-disposal
- Income-Generation
- Other (Please specify)……..

Q14 Do you have Anaerobic Digestion unit(s) installed in your farm?

- Yes
- No

If yes, please continue to Question 15

If no, please skip forward to Question 28

_____

Part 4a – Your First Hand Experiences With AD

Q15 What feedstocks do you use in your AD unit(s)?

……
……

Q16 What are the reasons for your decision to adopt AD? Please tick all that apply:

- Renewable energy promotion
- Waste-disposal
- Income-Generation
- Other (Please specify)……..

Q17a How effective had your AD unit been in achieving your goal(s)?

	Very effective	Quite effective	Somewhat effective	Not at all effective
Waste Management				
Energy Generation				
Income Generation				

Other (please specify below) □ □ □ □

……..

Q17b Please provide any further comments here you may have on the effectiveness of your AD unit, regarding the benefits and challenges experienced

……
……

Q18 How many years have you had the AD unit?……..

Q19 What is the capacity of your AD unit?

- □ 0 - 4kW
- □ 5kW - 10kW
- □ 11 - 50kW
- □ 51kW - 150kW
- □ 151kW - 500kW
- □ 501kW - 1,000kW
- □ 1,001kW +
- □ Do not know

Q20a How would you describe the link between your AD unit and the local community?

	Very Strong	Strong	Weak	Very Weak	None
The local community as a:					
source of feedstock	□	□	□	□	□
market to sell energy to	□	□	□	□	□
source of support for AD	□	□	□	□	□
source of opposition to AD	□	□	□	□	□

Q20b Please provide any further comments you may have here on the link between your AD and the local community:

……
……
……

_____

Part 4b – Your Views on *Incentives* for AD Adoption, and AD-Related *Regulations*

Q21 – Were there any specific incentives that encouraged you to adopt AD (for example, subsidies, specific sources of grants or loans, or taxation policies)?

……
……

Q22 Were there any specific regulations that encouraged you to adopt AD (for example legislation such as the Nitrates Directives)?

……
……

Q23 Have there been any policy changes since your adoption of AD that have lead you to reconsider that decision? (for example taxation policies, access to finance, controls over the use of waste products, the off-farm movement of food waste and digestate?

……
……

Q24 How do you ***expect*** AD incentives and regulations to change in the next five years?

……
……

Q25 What impacts do you expect these changes in incentives to have on ***your use of AD***?

……
……

Q26 What impact do you expect these changes to have on ***the on-farm uptake of AD in the UK***?

……
……

Q27 What financial/tax incentives, and regulations, ***would you like to see implemented***, to increase the on-farm uptake of AD in the UK?

……
……

Please skip forward to Question 30

_____

Part 5 – Non-Adopters: Your Decision Not to Adopt AD, and Your Opinions on AD

Q28 What are the reasons for your non-adoption (please tick all relevant answers)?

- ☐ Not suitable for my farming activities
- ☐ Lack of information about AD technologies
- ☐ Lack of access to finance
- ☐ Inadequate financial incentives
- ☐ Overly-burdensome regulation
- ☐ Unstable policy or uncertain future policy
- ☐ Problem with connectivity to the National Grid
- ☐ Taxation policies
- ☐ Access to finance
- ☐ Controls over the use of waste products
- ☐ The off-farm movement of food waste and digestate
- ☐ Other (Please specify)…….

……

Q29 if relevant, what financial/tax incentives, and regulations, would be required for you to consider adopting AD?

……
……

Please continue to Q30

_____

Part 6 – Questions about UK Government Energy Policies

Q30a In recent years, the UK Government has introduced a number of specific measures that are aimed at ensuring a secure supply of energy and reduce greenhouse gas emissions. Can you please indicate your level of awareness of each measure?

	Very aware	Somewhat aware	Know the name only	Not at all aware
UK Renewable Energy Roadmap	☐	☐	☐	☐
Renewable Obligation (RO)	☐	☐	☐	☐
Feed-in Tariffs (FiTs)	☐	☐	☐	☐
Renewable Heat Incentive (RHI)	☐	☐	☐	☐
Renewable Transport Fuel Obligation (RTFO)	☐	☐	☐	☐
Electricity Market Reform (EMR)	☐	☐	☐	☐
'Connect and Manage' Transmission Access Regime	☐	☐	☐	☐

Q30b Do you have further comments about any of these policies?

……
……

Q31 Finally – do you have any comments you wish to make about AD that you feel we have not covered at all, or adequately, above?

……
……

Part 6 – Questions about UK Government Energy Policies

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Feed-in Tariffs (FiTs)	☐	☐	☐	☐
Renewable Heat Incentive (RHI)	☐	☐	☐	☐
Renewable Transport Fuel Obligation (RTFO)	☐	☐	☐	☐
Electricity Market Reform (EMR)	☐	☐	☐	☐
'Connect and Manage' Transmission Access Regime	☐	☐	☐	☐

Q30b Do you have further comments about any of these policies?

……
……

Q31 Finally – do you have any comments you wish to make about AD that you feel we have not covered at all, or adequately, above?

……
……