Title page

On-Farm Anaerobic Digestion: a disaggregated analysis of the policy challenges for greater uptake

Hafez Abdo

(Corresponding Author)

Accounting Division. Nottingham University Business School (Si Yuan Centre, C 18d), University of Nottingham Jubilee Campus, Nottingham, NG8 1BB. E: hafez.abdo@nottingham.ac.uk; T: 0115 748 7570.

Rob Ackrill

Department of Economics, Nottingham Business School (NEW L8), Nottingham Trent University, Burton Street, Nottingham, NG1 4BU. E: robert.ackrill@ntu.ac.uk; T: 0115 848 4234.

On-Farm Anaerobic Digestion: a disaggregated analysis of the policy challenges for greater uptake

Abstract

In recent years, the multifunctionality of farming activities and diversification of on-farm income sources have increasingly included renewable energy generation. The uptake of on-farm anaerobic digestion (AD), however, continues to lag behind other renewable energy activities. Moreover, on-farm AD is not only a source of renewable energy, but also a means of farm waste management and thus a means of enhancing environmental quality. This paper provides an in-depth analysis of the policy barriers that might explain this limited uptake, and identify key directions for future AD policy design. We draw on a mixed-methods research design, with data collected by questionnaires, interviews and a round-table workshop of stakeholders. We analyse our data using a framework that disaggregates 'policy' into meta, meso and micro levels of Policy Means and Policy Ends. We conclude that future policy must recognise the synergies between on-farm AD as a source of renewable energy and as a means of waste management, reflected in instrument mix and instrument calibration. Calibration-stability is also found to be of critical importance. We also offer new insights and understanding around the application of our chosen policy framework, notably how it can analyse policies that are nested within large, complex policy systems.

Keywords: Agricultural Energy and Waste Systems; Anaerobic Digestion; Policy Design; Policy Ends and Means; Renewable Energy; Waste Management

Highlights

- Anaerobic digestion can provide renewable energy and on-farm waste management
- UK AD policy does not reflect the complementarities between these two benefits
- AD policies need to offer stability and certainty to promote uptake decisions
- Better policy design requires coordinated incentives, regulations and information
- Policy analysis is enhanced by looking at multiple levels of policy ends and means

On-Farm Anaerobic Digestion: a disaggregated analysis of the policy challenges for greater uptake

1. Introduction

The links between farming and renewable energy (RE) generation are strong. Factors driving this include farmers providing the space for land-based RE sources (RES), such as wind and solar, and farmers seeking to diversify income sources. Further, some RES derive from farming activities, such as on-farm anaerobic digestion (AD) utilising slurry and other animal and food waste[3]. However, the uptake in the UK of on-farm AD is limited, despite its dual benefits of RE generation and waste management (Ackrill and Abdo, 2000). In the context of the UK government's net zero strategy for 2050 (House of Commons, 2019; Priestley, 2019), on-farm AD offers the opportunity for a significant increase in RE generation from its current low base, whilst also contributing to wider environmental and biodiversity goals, as farm wastes can be significant sources of pollution (Environment Agency, 2018).

The aim of our research is to explore how policy can be understood as both a source of limited AD uptake and as a means of increasing uptake, in the context of the UK government setting itself this ambitious net emissions target. This should also be seen against the backdrop of a literature on AD that focuses on technical, economic and, to a lesser extent, behavioural factors, to the almost total exclusion of policy. From this we derive our primary research question: what are the policy drivers of on-farm AD uptake and what changes are needed to increase uptake? In addition, our research is also informed by the hypothesis that the lack of AD uptake is shaped by variations in government policy.

[3] We use the word 'waste' in this paper as a convenient shorthand, recognising that this may be a misnomer: 'An organic waste is merely an organic resource that is being handled inappropriately' (Bywater, 2011: viii).

The basis of this research is in-depth fieldwork conducted in the East Midlands region of England, specifically the counties of Derbyshire and Nottinghamshire, in 2016 and early 2017. Data collection has been undertaken in three stages: a (large-N) survey of farmers, followed by (small-N) interviews and a roundtable workshop, attended by multiple stakeholders. Given our particular focus on policy, data analysis is undertaken utilising a framework that allows us to disaggregate our unit of analysis, AD policy, into policy means and policy ends, each then divided into the meta, meso and micro levels (Cashore and Howlett, 2007; Howlett and Cashore, 2009). The resulting 2*3 matrix allows us to dissect and understand 'policy', as a concept, from which we can identify with considerable detail and nuance where the policy challenges lie in promoting the greater uptake of on-farm AD in the UK. Further, in applying the Cashore and Howlett framework to AD policy, we are able inductively to draw out new insights into this framework and its application and interpretation.

To this end, in the next section we review the extant research in this area, starting with state of play of RE generation in UK agriculture. We then summarise the main findings of our fieldwork, focusing in particular on policy issues. Next, we introduce the framework within which our data will be analysed, after which we offer our initial analysis. We conclude with a summary of our main findings and what they mean for policymakers, the AD sector and farmers.

2. Literature Review – On-Farm AD Uptake in the UK

There are several different literatures that refer to on-farm AD – notably general RE generation, on-farm RE generation, general AD uptake and on-farm AD uptake. Moreover, these literatures are all located with the overarching body of research on climate change mitigation and the transformation of the UK energy mix. We consider briefly below those

aspects most relevant to our subsequent analysis. First, we review UK energy policy very briefly, within which we locate the extent of on-farm RE generation.

2. 1. *Background – UK Energy Policy in Context*

UK energy policy is embedded in a complex multilevel governance structure. Domestically, the UK committed, in the 2008 Climate Change Act, to reduce greenhouse gas (GHG) emissions by 35% below 1990 levels by 2020, and 80% by 2050; the latter figure being raised to 100% ('net zero') in 2019 (Priestley, 2019, House of Commons, 2019; see also DEFRA, 2014, 2015). This exceeds its international obligations: the 20% reductions, by 2020, agreed by the UK as part of both the Kyoto Protocol and the 2009 European Union (EU) Renewable Energy Directive (RED), the latter no longer having legal relevance to the UK.

In 2019, UK GHG emissions have been estimated provisionally at 45.2% below 1990 levels (BEIS, 2020). Under the RED, the UK was committed to delivering a 15% share of RE in gross final energy consumption by 2020. By 2018, this figure stood at 11% (BEIS, 2019a: 122). Energy production from 'low carbon sources' in 2018, however, was 19% (BEIS, 2019b: 13). One-third of electricity generated was from renewable sources (BEIS, 2019b: 32): wind (51.7%), solar photovoltaics (11.7%), hydro (5%), landfill gas (3.5%), and other bioenergy (28%) (*ibid*), with two-thirds of bioenergy coming from plant biomass (BEIS, 2019a: 114). Overall, the UK is performing well in terms of GHG emissions reductions relative to targets, but the RE mix remains highly uneven.

Considering farming and RE activities further, farmers and farming activities are highly diversified. In 2018/19, 26% of farm income in England came from 'diversified activities' (£740mn out of a total of £2.88bn on diversified farms; DEFRA, 2019). This averages-out at £19,800, across the 65% of English farms that have diversified incomes –

although there will be considerable cross-farm variation. Solar is the dominant on-farm RE generation technology, located on twice the number of farms as all other RE sources combined. Total farm business income and output were nearly twice as high for farms with solar than for farms with other RES, but the latter generated a much higher income and output from their RES than those with solar (NB separate data for AD are not provided). This will also translate to high income and output per farm (see Appendix Tables A1 and A2). Regarding numbers of on-farm AD units, IEA Bioenergy (2020: 63) indicates 261 'agricultural' units in 2018; whilst the interactive map on the Anaerobic Digestion and Bioresources Association (ADBA) website identifies 374 'agricultural' units[4]. With FBS data for 2018/19 indicating 5,800 farms generating 'other' RE in total, AD uptake is clearly relatively very modest.

2. 2. *AD as a Waste Management System*

AD is not only a source of RE generation, but also a means of waste management (Klinkner, 2014). It has been used in sewage treatment for over a century and has been present on UK farms since the 1970s (Vutai et al., 2016). It is thus a technology known to be able to treat wastes, including the by-products and waste products of farming. Farm wastes, such as slurry, cannot really be **reduced**. Slurry can be **reused**, as a fertiliser, but there are practical limits to this, including having sufficient land area on which to spread it. Further, there are seasonal variations in the demand for the nutrients that slurry offers. Slurry cannot be **recycled**, but such farm wastes have to be dealt with, particularly in the context of their pollution potential. Figure 1 presents our own understanding of the waste hierarchy.

[4] As of 7 July 2020.

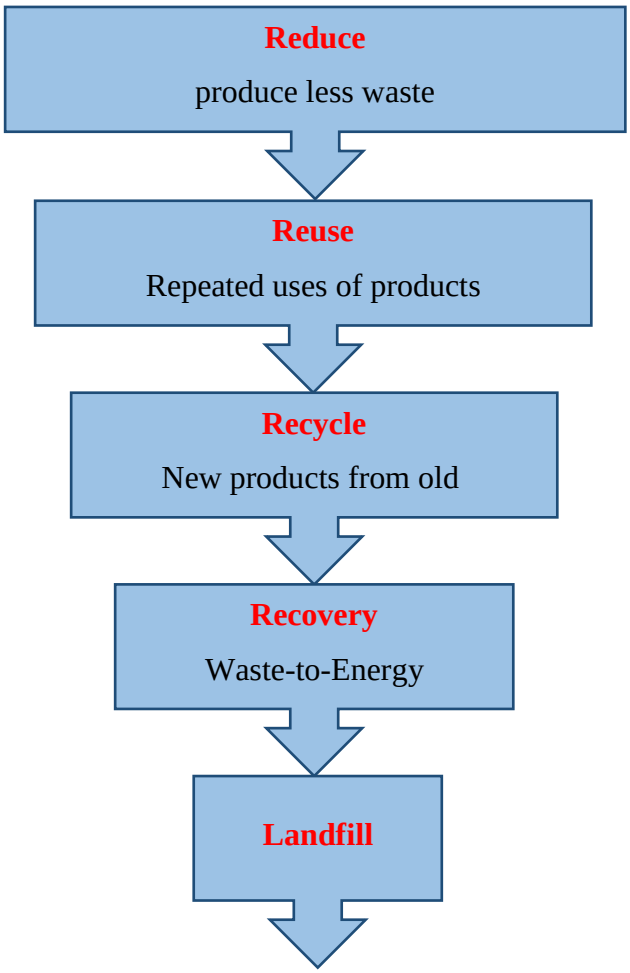


Figure 1: The Waste Hierarchy

The Environment Agency (2018: 13) reported that in 2017/18, of the top three regulatory sectors only agriculture saw a rise (by 13%) in serious pollution incidents. The following year there was a (coincidental) 13% fall in such incidents, with the dry summer in 2018 allowing farmers to spread slurry on their land for longer. There was thus less slurry in tanks over winter 2018/19 – a major source of pollution and a demonstration of the importance of effective farm waste management.[5]

[5] https://unearthed.greenpeace.org/2019/07/26/environment-agency-rivers-pollution-uk/ (last accessed 7 July 2020).

In terms of Figure 1, we are focusing on **recovery**, specifically recovery of energy from the (erstwhile) waste. This captures succinctly how farm wastes can be an input into AD which, in turn, generates: RE. The balance of the two functions of AD is, however, critically important. A focus primarily on RE generation could result in policy incentives for the growing and use of 'energy crops', crops with food and feed uses that can be grown specifically as an input into AD units. A focus primarily on waste management, however, could limit on-farm AD to a small number of large mixed or livestock farms.

One of the challenges in designing policy incentives that balance RE-generation and waste management is seen in the incentives for growing crops specifically for use in AD units. On the one hand, AD-as-waste-management is vulnerable to uneven supply of wastes, in particular if animals are kept outdoors in the summer months. On the other hand, growing energy crops raises concerns around the use of land for non-food uses, resulting in food v fuel debates. An important aspect of this debate is that farm wastes have a lower energy value (Hoolohan et al., 2019: 400). This could reduce the commercial incentive to utilise them in AD units, unless policy were designed specifically to account for this difference.

2. 3. *Anaerobic Digestion – primary research into on-farm uptake in the UK*

The extant literature most closely related to the present paper's research focus is very limited, with no study dedicated specifically to the policy aspects of on-farm AD uptake. In their literature review of manure management strategies (MMS), a topic that includes AD as one of several MMS, Niles et al. (2019: 11) find 36 articles since 1980, with only 12 in the 'past five years'. Their emphasis on the recent past reflects two concerns; first, that in contrast to an enormous literature on the technical aspects of MMS, there is very little work undertaken on social aspects; second, that there is hardly any *recent* work addressing social aspects.

Confirming this general message, there is very little work that has been undertaken to address the specific question of the drivers of on-farm AD uptake. Hoolohan et al. (2019)

include three on-farm AD operators in their sample of 15 in total, but we are aware of only four studies that analyse on-farm AD uptake specifically: Tranter et al. (2011), Tidy et al. (2015), Röder (2016), and Ackrill and Abdo (2020).

Each has a slightly different analytical focal-point: Tranter et al. (2011) sought to establish *ex ante* the energy-generating potential from on-farm AD (farmers across England were surveyed); Tidy et al. (2015) studied six farms with AD already adopted (in the South West region of England); and Röder (2016) focused on the possible land-use implications from growing energy crops for AD (in the East of England region). All three therefore utilised different methods of data collection: large-n questionnaire data (Tranter et al., 2011), small-n comparative case study (Tidy et al., 2015), and interviews, site visits and observation (Röder, 2016). Ackrill and Abdo (2020) adopt a three-stage mixed methods approach to data collection that complements and extends the approaches of the other three papers (they focus on the East Midlands region of England).

Common findings across the studies include, unsurprisingly, AD needing to deliver an adequate 'return' or 'profit'. The generation of RE is recognised 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.

On the question of growing energy crops (notably maize) specifically for use in AD units, this was seen quite differently to the intense debates around land-use and land-use change in the context of growing feedstocks for biofuels (Ackrill and Kay, 2014). Tidy et al. (2015, p. 274), merely observe that one way to boost AD uptake is to increase feed in tariffs (FiTs), 'to recognise energy crop costs'. Röder (2016, p. 79; see also Ackrill and Abdo, 2020) found that stakeholders were 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 positivity (or absence of criticality) amongst farmers in particular stands in contrast to arguments found in both the academic literature (Lijó et al., 2017) and in UK policy documents (DECC/DEFRA, 2011). In the present paper, it is important to distinguish between farmers choosing freely to grow energy crops for use in AD units as a business decision, and farmers growing energy crops as a result of targeted policy incentives.

In the research reported below, our research questions and research design take inspiration from the factors identified above in these few relevant studies. The present study is, however, the first to seek both an in-depth, unified understanding of the potentially multiple policy factors that might be holding back on-farm AD; and how policy change might be targeted to reduce those barriers; resulting from our detailed analysis of 'policy'.

3. Data Collection

Our research (see also Ackrill and Abdo, 2020), involved a three-stage mixed methods design – an approach that stands in contrast to most other papers discussed above. First, we distributed a questionnaire to farmers in the East Midlands counties of Derbyshire and Nottinghamshire. This combined open and closed questions, generating primarily qualitative responses (the quantitative data provided a profile of respondents – see Appendix Tables A3 and A4, and Appendix Figure A1). The regional National Farmers Union (NFU) office, on our behalf, sent questionnaires to its 1,586 registered members in these counties, in March

2016.[6] 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.).

Second, we conducted 18 in-depth interviews with AD stakeholders (see Table A5 for details). 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 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. Dissecting Policy – Analytical Framework

A critical part of policy analysis is to determine precisely the unit of analysis: policy. In order to explore potential policy (in)effectiveness and propose policy changes with the aim of delivering a different outcome, the different dimensions of a particular policy must be distinguished. To this end, in the present paper we draw upon the work of Ben Cashore and Mike Howlett (see, in particular, Cashore and Howlett, 2007; Howlett and Cashore, 2009; Howlett, 2011). Table 1 sets out their decomposition of policy. Drawing on Hall (1993), they identify three distinct levels of policy, labelled in Table 1 as the Meta, Meso and Micro levels. Cashore and Howlett then distinguish between policy ends and policy means – something that Hall refers to, but does not develop.[7]

Policy Level

[6] This may lead to a slightly biased sample, as not all farmers will be members of the NFU.

[7] Hall's work thus remains known principally for distinguishing between modest and endogenous first order (micro) and second order (meso) changes on the one hand, and exogenous third order (meta) paradigm change on the other.

		Governance Mode	*Policy Regime*	*Programme Settings*
		Meta-level	*Meso-level*	*Micro-level*
		High-level abstraction	*Programme-level operationalisation*	*Specific on-the-ground measures*
Policy Component	**Policy Ends**	**Goals:** abstract general policy aims	**Objectives:** operationalisable policy objectives	**Setting:** Specific policy targets
		The most general macro-level statement of govt aims and ambitions in a specific policy area	The specific meso-level areas that policies are expected to address in order to achieve policy aims	The specific on-the-ground micro-requirements necessary to attain policy objectives
	Policy Means	**Instrument Logic:** general policy implementation preferences	**Mechanisms/Instruments:** Policy tool choices	**Calibrations:** Specific policy tool calibrations
		The long-term preferences of govt in terms of the types of organisational devices to be used in addressing policy aims	The specific types of governing instruments to be used to address programme-level objectives	The specific 'settings' of policy tools required to attain policy targets

Table 1: A Taxonomy of Policy Decomposition

Sources: Adapted from Cashore and Howlett, 2007: 536; Howlett and Cashore, 2009: 39; Howlett, 2011: 17.

Using the Cashore and Howlett 2*3 matrix, we can take a policy and explore *what* it is trying to achieve and *how* it is trying to achieve it. From this, we can analyse policy dynamics over time with greater nuance, and we can disaggregate what we mean by 'policy change' – both in *ex post* analyses and in terms of forward-looking policy recommendations. This framework has been used before in the analysis of agricultural policy (Kay and Ackrill, 2010), but it remains relatively underutilised in energy policy analysis. It is also important to note that this is a framework, not a theory. Its use requires a degree of interpretation of different aspects of policy, given also that our research design includes the analysis of both interviews and qualitative responses to open questions on the questionnaire. That said, it is being used as the basis for analysing specific policies. As a result, we adopt a critical realist approach:

whatever people's opinions and concerns may be, they are analysed in the context of specific policies.

5. On-Farm Uptake of AD: A Critical Policy Analysis

In this section, we consider AD in the context, first, of the three levels of policy ends, going from the, highest, meta-level to the lowest, micro level of analysis. We shall then repeat this for policy means.

5. 1. AD, Policy Ends and Policy Means – an Introduction

When considering the **Policy Ends** for AD, what are the policy **Goals** towards which AD can contribute? AD contributes to two broad policy goals – the generation of RE and the management of waste and pollution. One of the question-marks over AD arises from this very fact: to what extent are these two broad goals reflected in policy design and implementation? The principal policy **Objective** of on-farm AD policy concerns on-farm AD uptake. In this, we are interested in both the promotion of on-farm AD and the factors that limit its potential uptake. At the micro-level, policy **Settings** seek to promote AD uptake. AD must be affordable to buy and economically viable to operate, without which it will not find a place in the farm business.

As for **Policy Means**, what is the **Instrument Logic** required to deliver on the Policy Ends? In cases especially of market-expansion beyond a small niche scale (Lazarevic and Valve, 2020), government intervention is needed to expand both supply and demand; where the market is delivering a socially sub-optimal outcome. In this context, instrument logic can take one or both of two forms: fiscal incentives and regulatory interventions. Following the Tinbergen Principle (see del Rio and Howlett, 2003; Knudson et al., 2017), we can argue that we need (at least) as many instruments as targets. In the current analysis, however, it becomes

clear that we also need to ensure an *appropriate and aligned* mix of instruments across the Instrument Logics of incentives and regulation. Indeed, it is clear that in the policy literatures, especially those related to energy and the environment, the relationships between instruments and targets is more complex than Tinbergen implies (see, *inter alia*, Knudson, 2009; del Rio and Howlett, 2013; Boscán, 2020).

From this, we can identify a range of **Mechanisms/Instruments** as the policy tools of choice. Possible incentives can include access to credit, grants and subsidies for the purchase of AD units; and FiTs for the generation of RE. Regulatory measures include oversight of planning processes, the movement of feedstocks onto and between farms to use in AD units, the use of digestate as a fertiliser and, controls on pollution, such as nitrate runoff. Turning to policy instrument **Calibrations**, again a distinction must be drawn between the fine-tuning of incentives and regulations. Examples regarding incentives include interest rates, collateral requirements and payback periods, the precise terms by which grants and subsidies are offered, and the level of FiTs. With regulatory interventions, are they mandatory or voluntary, what level of pollution, nitrate runoff, etc might be permissible, are regional variations required, and how practical is it for the farmer to obtain the necessary permissions to install AD on-farm and to operate it effectively?

5. 2. Policy and the Uptake of On-Farm AD – an Analysis of Qualitative Data

In Ackrill and Abdo (2020) we presented an analysis of stakeholder perceptions of the key barriers to greater on-farm AD uptake in the East Midlands region of England. This was based on a carefully-structured content analysis (Table 2). In the present paper, the specific focus on policy coding in our more narrowly-defined analysis still takes us into all of the themes and the sub-themes presented.

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

Table 2: Analytical Themes of Barriers to on-farm AD

Source: Ackrill and Abdo (2020: 5)

The first finding to report is that all stakeholders interviewed – and farmers surveyed – argued for the active involvement of policymakers in the promotion of AD. There is, in short, a strong demand for policy support for AD. The rest of this section considers, in greater detail, current policy 'supply', its limitations and where more policy action is felt to be needed from AD stakeholders' perspectives. We base this discussion around the structure of our policy taxonomy set out in Table 3, looking first at **Policy Ends**: goals, objectives and settings.

Considering first the broad policy **Goals** the foregoing discussion, confirmed in our fieldwork, highlights AD both as a source of RE generation and as a technology for waste (and pollution) management. The principal policy **Objectives** is then defined in our main research question – increasing the uptake of on-farm AD. That said, participants[8] also identified a series of factors (discussed in detail later) that, ultimately, put limits on the practical scale of increased on-farm uptake; factors that policymakers need to recognise in declaring their ambitions when designing on-farm AD policy. Finally, we consider policy

[8] We use 'participants' when referring to responses given both by interviewees and those who completed the questionnaire, and 'interviewees' when referring only to responses raised in interviews.

Settings, which seek to identify what is required in order to deliver on the policy objectives. From our research data we identify three principal categories of settings – affordability, economic viability and practicality.

We turn now to **Policy Means**: Instrument Logic, Mechanisms/Instruments and Calibrations. Having set out what policy seeks, or should be seeking, to achieve we now focus on how this can best be delivered. The first point is that there are many more **Instruments** than **Objectives**. A much closer parallel exists between **Instruments** and **Settings**, with the latter fine-tuned through the **Calibration** of the chosen **Instruments**. Although this observation is intended as a general insight into the structure and application of the 2*3 matrix, it also reflects a growing recognition of what has been called 'new policy design' (Howlett et al., 2015). This relates powerfully to the challenge facing AD policy, since it describes a situation where 'multiple tools are used over time in policy packages designed to address multiple goals, and upon more complex multi-policy and multi-level design contexts' (Howlett et al., 2015: 291). We discuss this further below, when we reflect on the application of the 2*3 matrix in policy analyses.

There are two dominant **Instrument Logics** at play in the promotion of on-farm AD: (fiscal) incentives and regulation (sometimes referred to, respectively, as market-based and command-and-control). This derives closely from the (environmental) economics literature (of which Hahn and Stavins, 1992, is an early example). These concepts capture the essence of a literature starting with Lowi (1964, cited in Peters, 2015; and Cairney, 2020), who identified policy responses as involving regulatory, distributive, redistributive and constituent (as described in, *inter alia*, Cairney, 2020: 21). The second and third of these categories are distinct types of fiscal intervention, whilst the fourth is contextual, referring to 'policies designed to shape the formation of other policies' (Peters, 2015: 65).

Whilst both RE generation and improving the management of wastes have considerable societal value, their delivery cannot be presumed simply by farmers 'doing the right thing' via their farm businesses. They are concerned primarily with the private costs and benefits of their activities. In the context of both Policy Goals and Policy Objectives, our research confirmed the need for both regulations and policy incentive in instrument-design to deliver more on-farm AD. In this regard we recall the merit-good argument for government intervention in a market. Without policy intervention there may be on-farm AD uptake, but it will be below a socially-optimal level.

In addition to incentives and regulation, a significant feature of our fieldwork was the extent to which information was lacking – with regard to many aspects of AD as a commercial opportunity and the decision-making process around AD-adoption – a situation that many farmers in particular were aware of and wanted to be corrected. We thus include **Information Provision** as an instrument logic. That said, this is not something that is exclusive to governments and public policy. As is clear from Table 1, the Cashore and Howlett framework was designed to focus on public actors and policies. In practice, however, in many cases non-governmental actors are involved in the policy process. We thus propose that this framework can be interpreted to accommodate non-governmental actors and actions in a way that reflects governance more broadly.

Mechanisms/Instruments are the tools that policymakers use to deliver policy outcomes. We summarise these in Table 3. These have been identified from a content analysis of the responses to open questions on the survey and the interview data. These have, in turn, been separated into incentive and regulatory instruments. Following on from the foregoing, we also include information as a key instrument. Participants identified a number of issues about which they wanted to know more. These included how AD could fit into

existing farm systems, the nature and consequent economic effects of using different feedstocks in the AD unit, and details around the planning process for AD.

Turning finally to policy **Calibrations**, whilst both an appropriate mix of instruments and alignment with objectives are necessary conditions for policy success, so too is appropriate policy calibration. They will determine both the practicality of investing in AD and the economic viability of such an investment. A separate, but deeply interconnected, aspect of calibration highlighted by several respondents as deterring investment was for a lack of calibration-stability. This is seen most strikingly with incentive-related calibrations, in particular relating to FiTs and the Renewable Heat Incentive (RHI).

With regulation, calibration can take different forms. It can, like fiscal incentives, refer to specifically-calibrated values, for example nitrate levels in water courses, whether there is need or merit in setting regional variations in such indicators, etc. More broadly, calibration can refer to whether a policy is mandatory or voluntary. Generally, the word 'regulation' implies mandatory policy targets – that is, it takes the form of hard law and is thus legally enforceable. That said, even a voluntary approach to 'regulation' (in the form of soft law) has been shown to deliver significant desired policy responses (Ferrero Ferrero and Ackrill, 2016). Once again, information featured heavily in participant responses relevant to questions of instrument calibration.

	Governance Mode	Policy Regime	Programme Settings
Ends	***Goals***	***Objectives***	***Settings***
	Renewable energy generation Waste and pollution management	Increased on-farm AD uptake (recognising the notional upper limit)	Affordable to adopt Practical to adopt Affordable to run
Means	***Instrument Logic***	***Mechanisms/Instruments***	***Calibrations***
	Incentives (fiscal) Regulation Information provision	(*Incentives*) - credit/grants/subsidies for AD purchase - Feed-in Tariffs - Renewable Heat Incentive (*Regulation*) - planning process - feedstock movements - digestate use as fertiliser - controls on pollution, runoff, etc. *Information-*	(*Incentives*) - interest rates - collateral requirements - payback periods - grant/subsidy terms and conditions - Feed-in Tariff levels - Renewable Heat Incentive tariffs (*Regulation*) - mandatory versus voluntary - acceptable pollution/runoff levels - regional variations *Information-*

Table 3: Policy Ends, Policy Means and On-Farm Anaerobic Digestion Uptake – a summary of key themes

5. 3. Discussion of Findings and Future Policy Directions

In this section, we reflect on the data analysis, summarised in Table 3, and the implications this has for both our understanding of policy and for possible future directions that AD policy can take. The key findings are then summarised in Table 4. The first point to note from Table 3 is that the key focus of this research, promoting on-farm AD adoption, is located at the Policy Regime level. In other words, on-farm AD uptake is itself a means to an end (strictly, to two ends). The analysis presented here is, in effect, nested within higher-level ambitions related to combatting climate change and environmental degradation. This is an important point in the context of understanding and applying the 2*3 matrix of Cashore and Howlett in policy analysis. In the language of economics modelling, it is a partial equilibrium framework, a snapshot of one specific 'policy' that, in practice, exists both in time and in relation to other policies.

There are two aspects of **Policy Ends** that require further exploration, building on the foregoing analysis. First, several participants expressed concern that the distinct aspects of RE generation and waste management were not being considered in a joined-up way. This is then reflected in both Instruments and Calibrations, where multiple incentives and regulations are in place, but without substantive consideration of the extent to which the two Policy Goals are linked symbiotically. For example with incentives, FiTs and the RHI reflect renewable energy considerations, without incorporating the societal benefits from improved waste management. With regulations, rules enabling the movement of wastes between farms could enhance the economic viability of on-farm AD units, as well as strengthening the waste management potential of AD.

Second, there is crucial point on Policy Ends, not captured in Table 3, that requires further consideration. Whilst there is broad agreement across participants in terms of all levels of Policy Ends, there also exist practical limits to the scale of potential on-farm AD

uptake and, therefore, to its potential contribution to RE generation and farm waste management. This, in turn, limits the extent to which on-farm AD can contribute to the higher-level goals of combatting climate change and environmental degradation. We consider now the factors that were identified by participants.

A key problem is simply that AD is not seen as a suitable investment by many farmers, given its perceived incompatibility with several types of farming activity. 56% of respondents to our survey reported that it was not appropriate for their farm business. Only some types of agriculture generate the type and quantity of wastes suitable for use in AD units, with only some requiring careful management (essentially slurry and manure). Even where AD is compatible with existing farm business activities, there is still the issue of reliable and steady feedstock supply. Problems can arise where animals are grazed outdoors for a part or much of the year. This issue was raised only by farmers, but several of them made this point. This raises the possibility that AD is most suitable for farms that operate less animal welfare-friendly policies regarding indoor housing.

Even if regulations on the movement of wastes are relaxed to smooth the supply of feedstock, as noted above, there might be a limit to the land area on which the resulting digestate can be spread as a fertiliser, unless regulations on its transport and use are also adjusted. A further point raised by a number of participants related to the size of AD units that are available. This affects the ability to purchase a unit (see below), but it also relates directly to the scale of demand for feedstock required to run the AD unit efficiently.

Turning to **Policy Means**, there was not only acceptance of a role for government action, but a strong desire for government intervention in the market. There were, as a result, no responses that questioned the two Instrument Logics identified in Table 3. There were, however, plenty of comments relating to both Policy Instruments and Policy Calibrations. We

consider first specific fiscal incentives, followed by regulations. The role of information is incorporated into this discussion, as appropriate.

Affordability was raised by many participants as a critical factor. This, of itself, is unsurprising, but the concerns expressed indicate the scale of the problem. In terms of the ability to purchase an AD unit, participants suggested targeted credit, grants and subsidies as instruments that could help this. Even if these were not provided directly by government, a number of participants argued that they could be underwritten by government. A related aspect was concern over the size of the AD unit. This is a factor that not only affects the purchase price, but most other economic aspects of the purchase decision. A specific issue that some participants raised was the cost of purchasing an AD unit by tenant farmers. As one put it, they would be investing a large amount of money in someone else's business.

The foregoing discussion refers to the affordability of AD, regardless of which Policy Goal is being pursued. Other fiscal incentives relate specifically to AD as a source of RE generation. Key among these, as confirmed by almost all interviewees (see also Hoolohan et al., 2019: 400, for AD more widely) is the FiT, with several interviewees also highlighting the role of the RHI. Moreover, whilst the FiT was highlighted as being a critical factor in the decision to purchase an AD unit, some interviewees highlighted the fact that as the FiT was being reduced by the government, so some operators were moving increasingly from electricity generation to Combined Heat and Power (CHP), in order to be eligible for the RHI (given also, one participant noted, that recipients earn more for heat-generation than for electricity).

With all incentive-based instruments, calibrations are critical to an individual's decision over AD uptake. With FiTs and the RHI, however, a number of participants expressed concern about the negative effect that changes in the FiTs and RHI incentives had on the decision to invest. One interviewee reported that funding for some planned AD

projects had been withdrawn as a direct result of government reductions in FiTs. More generally, and consistent with basic economic theory, uncertainty reduces investment – but this applies *a fortiori* to investments that are dependent on an adequate level of FiT in the first place. This also links to the question of payback periods, itself an important calibration, given that adequate FiTs need, ideally, to be guaranteed for a long time (several interviewees mentioned 20 years). Finally, an issue related to certain locations, raised by a small number of participants, is whether a farm is connected to the grid. If not, AD can still deliver waste management and generate electricity (and possibly heat as well) as an offset to purchased inputs. But in such a situation it would only be eligible for a generation tariff, not as well an export tariff (although only one interviewee drew this distinction).

Turning to regulatory instruments and their calibration, a distinction can be drawn between planning processes on the one hand and a series of instruments that are environmental in their focus. A great many participants expressed concern over planning issues, with some admitting a lack of understanding of the planning process. No participant argued for the removal of planning regulations, but there was strong support for a more relaxed approach to planning than at present for on-farm AD. There was also concern expressed over the costs involved, especially given the uncertainty of outcome. One locality-specific concern raised by some participants was that farmers operating in the Peak District National Park faced specific constraints in their activities.

One set of issues raised connected planning and environmental regulations. Considering planning issues first, a number of these link with information provision. Several participants, and not only farmers, believed that the restrictions on the movement of wastes, especially between farms, were excessive. This, however, would increase traffic flows, that could affect local communities and which planners would have to balance against the benefits of AD. It also links to an issue linking planning and information that a number of participants

raised: a lack of understanding of AD amongst planners and local communities. One example given was the question of odours: experience showed a belief that AD would increase, rather than mitigate, farm odours (see also Niles et al., 2019: 8). More than one interviewee also referred to the frustration of dealing with locals who opposed AD on the basis of 'not in my back yard' and 'anti-stuff' arguments. In response, one participant with experience of both sides of the planning process advised that farmers thinking of getting an AD unit should engage actively and positively with local communities and with planning officers from the outset.

Looking further at the question of information, we sought to understand farmers' awareness of a range of incentive- and regulation-based policy instruments. Responses are summarised in Figure 2. This distribution was confirmed by the interview data, where FiTs and the RHI were discussed by most interviewees, some mentioned the Renewables Obligation, a few mentioned the Renewable Transport Fuel Obligation (all of them to confirm its irrelevance to on-farm AD), a small number were aware of the Roadmap and nobody mentioned the others. In addition, 21% of questionnaire respondents gave lack of information about the AD technology itself as a barrier to adoption.

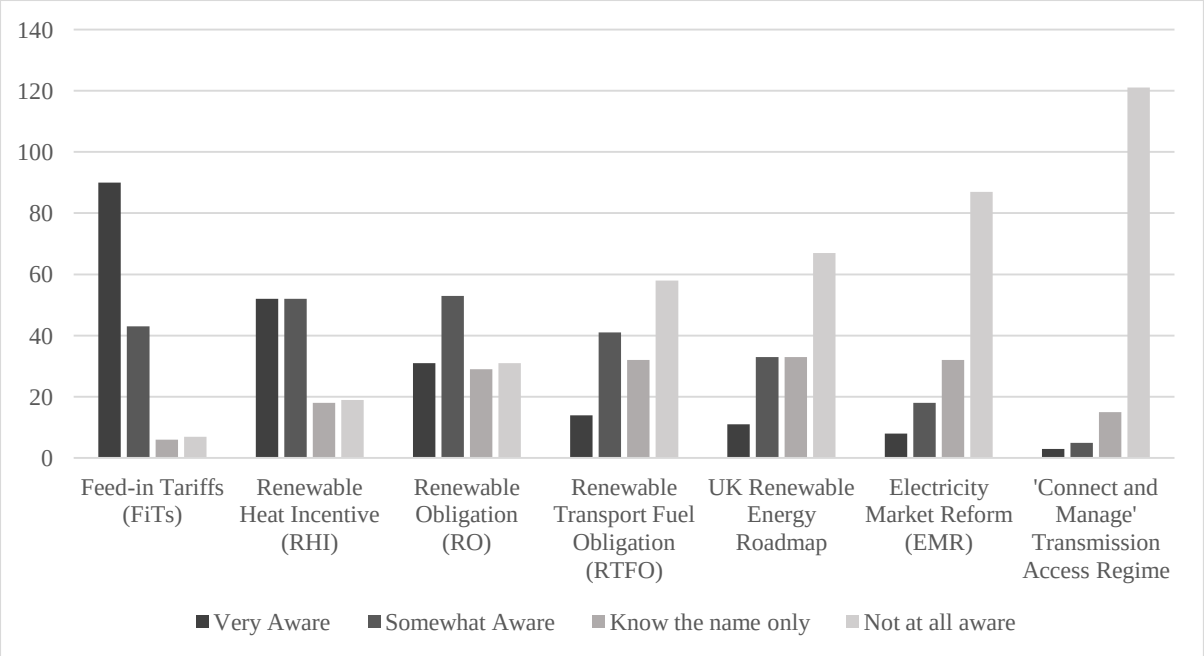


Figure 21: Awareness of UK Government RE Policy Measures and Instruments

Several years ago, Bywater (2011: 36) called for 'a single and definitive point of information for regulations surrounding anaerobic digestion'. The foregoing leads us to repeat this call. The Anaerobic Digestion and Bioresources Association (ADBA) is an extremely important industry body, but it is itself a stakeholder. The Waste and Resources Action Programme (WRAP) is active in this area, yet the fact remains: the uptake of on-farm AD remains very modest. WRAP offers a potential model for what Bywater called for, but WRAP itself, as structured currently, is focused more on waste resources than renewable energy generation, and operates across a wide range of waste-producing sectors. Expanding the resources for WRAP, or establishing an AD-specific body, has resource implications, but these must be judged in relation to both waste management and RE generation considerations. We summarise the key features from this reflection on our findings in Table 4.

	Governance Mode	Policy Regime	Programme Settings
Ends	***Goals***	***Objectives***	***Settings***
	Widespread agreement on the two goals	Opportunities to increase on-farm uptake Limitations must also be recognised	Viability: economic and environmental Practicality
Means	***Instrument Logic***	***Mechanisms/Instruments***	***Calibrations***
	Widespread support for government intervention, with the promotion of social goals through private actions steered by incentives and regulation Merit-good argument for policy action Includes information-provision	(*Incentives*) Supply of information about AD – addressing both policy and technology Help to purchase AD FiTs and the RHI (*Regulation*) A robust but enabling planning process Appropriate regulation of feedstock and digestate movements	(Incentives) - interest rates - collateral requirements - payback periods - grant/subsidy terms and conditions - feed-in tariff levels Stability of incentives (*Regulation*) Clear, practical and stable regulation

Table 4: Policy Ends, Policy Means and On-Farm Anaerobic Digestion Uptake – a summary of policy implications

We turn now to an issue that was raised by many participants and about which widely-contrasting views were expressed: the use of energy crops in AD units and whether this should be encouraged by policy incentives. On the one hand, and consistent with the limited existing literature outlined earlier, some farmers saw no problem with growing crops for non-food uses – several argued that agriculture has never been only about growing food – although only two farmers who responded to our questionnaire were currently growing crops to supply (other peoples') AD units. On the other hand, there was a strongly-held view against providing explicit policy incentives for this purpose. Some of our participants specifically argued against following the German model (see Blumenstein et al., 2015), and the large number of AD units fed by energy crops grown for the purpose, to illustrate what they did not want to see happen in the UK. The crucial distinction is between farmers who choose to grow energy crops for sale to AD unit operators as part of their normal business, and those who do this motivated by policy incentives.

Given that there was strong opposition to the introduction of an energy crop payment as an instrument of AD policy, the focus then turns to why there might be demand for energy crops. This brings us back to an earlier point – the need for a regular and adequate supply of feedstocks for the AD unit. As noted above, seen purely as a means of waste management, AD units might struggle to get such assured supplies in appropriate quantities, especially without relaxation of regulations on the movement of farm wastes. Several interviewees highlighted the need to grow energy crops in order to ensure the economic viability of an AD unit.

This captures a concern that, as a final point, takes us back to Policy Goals: the dual-purpose of AD as a means of RE generation and as a means of farm waste management. The irony here is that both deliver positive environmental impacts, yet AD policy hardly, if ever, recognises this symbiosis. It is clear that multiple factors influence the economic viability of

on-farm AD, without which the environmental benefits will be lost. These are shaped not only by the mix of policy instruments, across incentives and regulation, but also by their calibration – all enhanced by appropriate information-provision. The analytical framework of Cashore and Howlett helps us to make a crucial point: with two policy goals, that are synergistically linked, failure to recognise these synergies in the design of the policy means is likely to lead to compromised outcomes.

6. Conclusions and Policy Implications

The uptake of on-farm AD in the UK is limited. The purpose of this paper has been to analyse the policy challenges faced, thus to identify forward-looking opportunities. Our analysis has drawn upon the framework developed by Ben Cashore and Mike Howlett, which disaggregates our dependent variable, policy, into three levels each (meta, meso and micro) of Policy Ends and Policy Means. This has then been applied to an analysis of data obtained from questionnaires, interviews and a workshop. We have found broad support for on-farm AD as a source of RE generation and waste management. We have also found strong support for government intervention, via both fiscal incentives and regulatory measures. We have identified a range of policy instruments in place but, given the limited uptake of on-farm AD, highlighted questions about the current instruments, instrument-mix, and instrument calibrations.

We have also offered new insights into the work of Cashore and Howlett and its practical application in policy analysis. First, its original design focused on public (government) policies. In practice, policy governance involves non-governmental actors as well. This is seen most significantly in the detailed analysis of policy instruments and calibrations. Whilst the two principal Instrument Logics of fiscal incentives and regulation lead to public policy instruments, the critically important aspect of information-provision does not, perhaps should not, rely on government alone.

Second, we have shown how the Cashore and Howlett framework offers a partial equilibrium analysis. Hence we have seen that the goal of greater AD uptake exists at the meso rather than the meta level, whilst the AD Policy Goals of RE generation and waste management are themselves means to higher ends: environmental sustainability and climate change mitigation. This in no way devalues its importance of usefulness. Indeed, it is one of the great benefits of the Cashore and Howlett framework that it allows us to understand and analyse individual elements of a super-wicked policy problem in a way that offers practical policy insight on a manageable scale.

One such insight, and a key observation made by a number of participants, is that UK AD policy does not reflect well the balance between RE generation and waste management. Emphasis on RE generation shifts the focus towards ensuring the most energy-rich feedstocks are produced for use in the AD unit, including energy crops grown on farms specifically for this purpose. We have shown that with the policy instruments currently in place, notably FiTs and the RHI, and the evolution of their calibration, these have encouraged the use of energy crops even without the presence of any crop-specific incentive. AD for waste management offers important environmental benefits, but an AD policy that delivers both economic and environmental viability remains to be developed.

Policy is multidimensional, thus policy responses need to be several, coherent and consistent. They also need to offer stability and certainty, enabling farmers to make long-term planning decisions with a degree of confidence. In our dissection of policy into three levels of Policy Ends and Policy Means, we have shown how our understanding of 'policy' as a dependent variable can be enhanced, and how welfare-enhancing policy change can be approached and designed in a more nuanced and targeted way.

In so doing, we wish to point the way for further research on AD-uptake. Much of the (limited) literature about on-farm AD adopts a quantitative modelling approach to estimating

its potential. From our research, we see that RE generation potential is both determined and limited by feedstock availability, especially the availability of wastes. Wastes can be brought-in from off-farm, but that has transportation and emissions implications. Different feedstocks have different energy potentials. A participant in our Workshop made the point that, as a result of these variations, every AD unit is unique in its technical performance, therefore in its economic performance. Can modelling efforts reduces the degree of uncertainty over AD performance, encouraging more AD uptake? Can this be fed back to policy, to enable greater recognition of and balance between economic and environmental performance? Can research inform adaptations to the planning process? With on-farm AD uptake still modest, there remains much scope for research that can provide an evidence-base capable of assisting policymakers to change this situation, to the benefit of the rural economy and the environment.

Acknowledgments

This research study was funded by British Academy/Leverhulme small research grant SG142461, SRG Round 2014-15. We thank the BA for their financial support allowing us to undertake this study.

References

Ackrill, R. and Abdo, H. (2020) On-Farm Anaerobic Digestion Uptake Barriers and Required Incentives: A case study of the UK East Midlands region. *Journal of Cleaner Production*, 264, 121727. https://doi.org/10.1016/j.jclepro.2020.121727.

Ackrill, R. and Kay, K. (2014) *The Growth of Biofuels in the 21st Century: Policy Drivers and Market Challenges*. London: Palgrave.

BEIS (2019a) *Digest of United Kingdom Energy Statistics (DUKES) 2019*. Available at: https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2019 (last accessed 7 July 2020).

BEIS (2019b) *UK Energy in Brief, 2019*. Available at: https://www.gov.uk/government/statistics/uk-energy-in-brief-2019 (last accessed 7 July 2020).

BEIS (2020) 2019 *UK greenhouse gas emissions, provisional figures*. 26 March 2020. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/875482/2019_UK_greenhouse_gas_emissions_provisional_figures_statistical_summary.pdf (last accessed 7 July 2020).

Blumenstein, B., Siegmeier, T., Bruckhaus, C., Anspach, V. and Möller, D. (2015) Integrated Bioenergy and Food Production—A German Survey on Structure and Developments of Anaerobic Digestion in Organic Farming Systems. *Sustainability*, 7, 10709-10732.

Boscán, L.R. (2020) European Union Retail Electricity Markets in the Green Transition: The quest for adequate design. *WIREs Energy and Environment*, 9, e359. DOI: 10.1002/wene.359.

Bywater, A. (2011) *A Review of Anaerobic Digestion Plants on UK Farms - Barriers, Benefits and Case Studies*. Royal Agricultural Society of England. Available at: http://www.fre-energy.co.uk/pdf/RASE-On-Farm-AD-Review.pdf (accessed 24 July 2015).

Cairney, P. (2020) *Understanding Public Policy: Theories and issues*, 2nd ed. London: Red Globe.

Cashore, B. and Howlett, M. (2007) Punctuating Which Equilibrium? Understanding Thermostatic Policy Dynamics in Pacific Northwest Forestry. *American Journal of Political Science*, 51, 532-551.

DECC/DEFRA (2011) *Anaerobic Digestion Strategy and Action Plan: a commitment to increasing energy from waste through anaerobic digestion*. Department of Energy and Climate Change and Department for Environment, Food and Rural Affairs. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69400/anaerobic-digestion-strat-action-plan.pdf (accessed 12 April 2018).

DEFRA (2014) *Energy from Waste: A Guide to the Debate*. February 2013. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/284612/pb14130-energy-waste-201402.pdf (accessed 27 June 2015).

DEFRA (2015) *Anaerobic Digestion Strategy and Action Plan – Annual Report 2014*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/406928/pb14019-anaerobic-digestion-annual-report-2013-14.pdf (accessed 3 July 2015).

DEFRA (2018a) *The National Adaptation Programme and the Third Strategy for Climate Adaptation Reporting: making the country resilient to a changing climate*. Available at: https://www.gov.uk/government/publications/climate-change-second-national-adaptation-programme-2018-to-2023

DEFRA (2019) *Farm Accounts in England: Results from the Farm Business Survey 2018/19*. Available at: https://www.gov.uk/government/statistics/farm-accounts-in-england (last accessed 7 July 2020).

Del Rio, P. and Howlett, M. (2013) Beyond the "Tinbergen Rule" in Policy Design: Matching Tools and Goals in Policy Portfolios. *Annual Review of Policy Design*, 1, 16 pages. Available at: https://ojs.unbc.ca/index.php/design/article/view/534 (last accessed 13 July 2020).

Environment Agency (2018) Annual Report and Accounts for the Financial Year 2017 to 2018. Available at:

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/725117/Environment_Agency_annual_report_and_accounts_2017_to_2018.pdf

Ferrero Ferrero, I. and Ackrill, R. (2016) Europeanization and the Soft Law Process of EU Corporate Governance: How has the 2003 Action Plan Impacted on National Corporate Governance Codes? *Journal of Common Market Studies*, 54(4), 878-895.

Hahn, R.W. and Stavins, R.N. (1992) Economic Incentives for Environmental Protection: Integration theory and practice. *American Economic Review*, 82, 464-468.

Hall, P.A. (1993) Policy Paradigms, Social Learning and the State. *Comparative Politics*, 25, 275-296.

Hoolohan, C., Soutar, I., Suckling, J., Druckman, A., Larkin, A. and McLachlan, C. (2019) Stepping-Up Innovations in the Water-Energy-Food Nexus: A case study of anaerobic digestion in the UK. *The Geography Journal*, 185, 391-405.

House of Commons (2019) Acting on Climate Change: The Plan for Net Zero Emission in the UK. Available at: https://commonslibrary.parliament.uk/insights/acting-on-climate-change-the-plan-for-net-zero-emissions-in-the-uk/. (last accessed 18 July 2020).

Howlett, M. (2011) *Designing Public Policies: principles and instruments*. London: Routledge.

Howlett, M. and Cashore, B. (2009) The Dependent Variable Problem in the Study of Policy Change: understanding policy change as a methodological problem. *Journal of Comparative Policy Analysis*, 11, 33-46.

Howlett, M., Mukherjee, I. and Woo, J.J. (2015) From tools to toolkits in policy design studies: the new design orientation towards policy formulation research. *Policy & Politics*, 43, 291-311.

IEA Bioenergy (2020) *IEA Bioenergy Task 37 Country Report Summaries 2019*. Available at: http://task37.ieabioenergy.com/country-reports.html?file=files/daten-

redaktion/download/publications/country-reports/Summary/IEA%20Task%2037%20Country%20Report%20Summaries%202019.pdf (last accessed 12 July 2020).

Kay, A. and Ackrill, R. (2010) Problems of Composition, Temporality and Change in Tracing the Common Agricultural Policy Through Time. *Journal of European Integration History*, 16, 123-141.

Klinkner, B. (2014) Anaerobic Digestion as a Renewable Energy Source and Waste Management Technology: What Must Be Done for this Technology to Realize Success in the United States? *University of Massachusetts Law Review*, 9, 68-96.

Knudson, W.A. (2009) The Environment, Energy, and the Tinbergen Rule. *Bulletin of Science, Technology & Society*, 29, 308-312.

Lijó, L., González-García, S., Bacenetti, J. and Moreira, M.T. (2017) The environmental effect of substituting energy crops for food waste as feedstock for biogas production. *Energy*, 137, 1130-1143.

Maye, D., Ilbery, B. and Watts, D. (2009) Farm diversification, tenancy and CAP reform: results from a survey of tenant farmers in England. *Journal of Rural Studies*, 25, 333-342.

Niles, M.T., Horner, C., Chintala, R. and Tricarico, J. (2019) A Review of Determinants for Dairy Farmer Decision Making on Manure Management Strategies in High-Income Countries. *Environmental Research Letters*, 14, 053004. https://doi.org/10.1088/1748-9326/ab1059.

Peters, B.G. (2015) *Advanced Introduction to Public Policy*. Cheltenham: Edward Elgar.

Priestley, S. (2019) *Net Zero in the UK*. House of Common Library Briefing Paper CBP8590. Available at: https://researchbriefings.parliament.uk/ResearchBriefing/Summary/CBP-8590 (last accessed 7 July 2020).

Röder, M. (2016) More than food or fuel. Stakeholder perceptions of anaerobic digestion and land use; a case study from the United Kingdom. *Energy Policy*, 97, 73-81.

Tidy, M., Wang, X. and Hall, M. (2015) Prospects for on-farm anaerobic digestion as a renewable energy technology in the UK: learning from early adopters. International Journal of Business Performance and Supply Chain Modelling. 7(3), 256-277.

Tranter, R.B., Swinbank, A., Jones, P.J., Banks, C.J. and Salter, A.M. (2011) Assessing the potential for the uptake of on-farm anaerobic digestion for energy production in England. *Energy Policy*, 39, 2424–2430.

Vutai, V., Ma, X. and Lu, M. (2016) The Role of Anaerobic Digestion in Wastewater Management. *EM: Air and Waste Management Association's Magazine for Environmental Managers*, 66, 12-16.

Online Appendix – Included here for ease of reference in reviewing

Table A1: Farm Business Income (FBI) from diversified enterprises, England – 2018/19

	No. of farms	% of farms	Total FBI for these farms (£m)	Income of diversified enterprise (£m)	Average enterprise income(a) (£/farm)
Farm Business Income (incl. diversification)	57,100		2,876		
Farms which engage in:					
Diversified enterprises (all kinds)	37,400	65%	2,287	740	19,800
letting buildings for non-farming use	25,200	44%	1,753	454	18,000
processing/retailing of farm produce	5,800	10%	353	89	15,300
sport and recreation	7,100	12%	540	37	5,200
tourist accommodation and catering	3,700	7%	216	33	9,000
solar energy	11,600	20%	918	31	2,700
other sources of renewable energy(b)	5,800	10%	487	56	9,600
other diversified activities	5,900	10%	318	39	6,600

Source: DEFRA, 2019: 23.

Notes: (a) Average here refers to the mean calculated over farms which have that enterprise.

(b) Other sources of renewable energy includes power generating, wind turbines, anaerobic digestion and renewable heat initiatives.

Table A2: Value of farm business output FBO) from diversified enterprises, England – 2018/19

	No. of farms	% of farms	Total FBO for these farms (£m)	Income of diversified output (£m)	Average enterprise output(a) (£/farm)
Farm Business Output (incl. diversification)	57,100		18,202		
Farms which engage in:					
Diversified enterprises (all kinds)	37,400	65%	14,172	1,360	36,400
letting buildings for non-farming use	25,200	44%	10,843	630	25,100
processing/retailing of farm produce	5,800	10%	1,841	212	36,400
sport and recreation	7,100	12%	2,810	107	15,100
tourist accommodation and catering	3,700	7%	1,332	89	23,900
solar energy	11,600	20%	5,888	79	6,800
other sources of renewable energy(b)	5,800	10%	3,035	125	21,400
other diversified activities	5,900	10%	2,102	117	19,900

Source: DEFRA, 2019: 24.

Notes: (a) Average here refers to the mean calculated over farms which have that enterprise.

(b) Other sources of renewable energy includes power generating, wind turbines, anaerobic digestion and renewable heat initiatives.

Table A3: 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

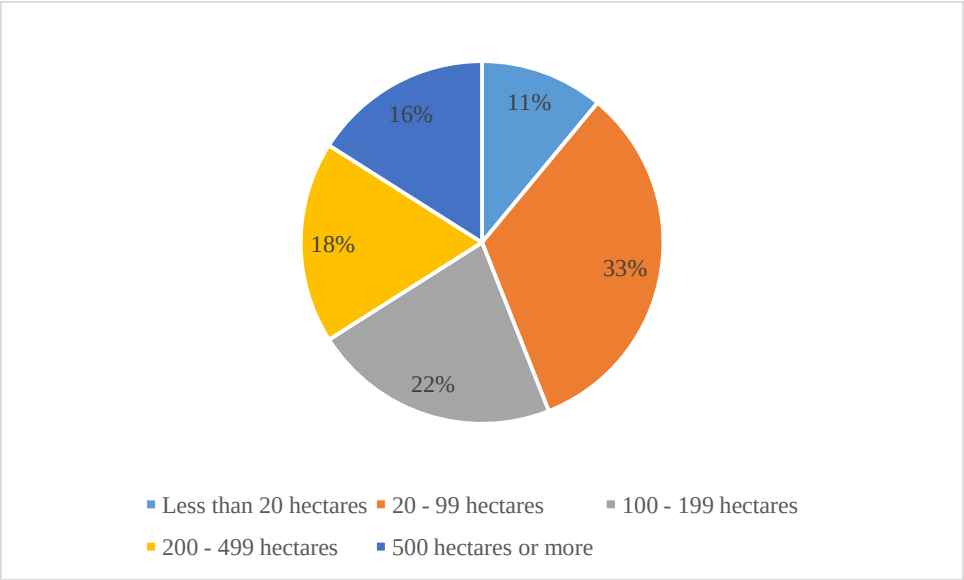
Table A4: Distribution of Animal-Based Farms in the Questionnaire Sample

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

Table A5: Profile of Interviewees

Interview Date	Interviewee profession	Code	Years of Experience	Interview duration	Mode of Interview
02-Aug-16	NFU – Trade association	NFU1	4 years in NFU – 30 Years as farmer	33 mins	Face-to-face
03-Aug-16	Farmer - Owner	FARM1	40 years	46 mins	Face-to-face
05-Aug-16	Farmer - Partner	FARM2	13 years	40 mins	Face-to-face
08-Aug-16	Farmer - Partner	FARM3a FARM3b	42 years	27 mins	Face-to-face
09-Aug-16	Farmer - Partner	FARM4	45 years	26 mins	Face-to-face
11-Aug-16	Farmer - Partner	FARM5	60 years	34 mins	Face-to-face
11-Aug-16	AD Installer – Managing Director	ADOP1a ADOP1b	20 years	47 mins	Face-to-face
12-Aug-16	Farmer - Partner	FARM6	60 years	27 mins	Face-to-face
15-Aug-16	Farmer - Owner	FARM7	30 years	22 mins	Face-to-face
16-Aug-16	Farmer - Owner	FARM8	35 years	40 mins	Face-to-face
17-Aug-16	Farmer - Owner	FARM9	36 years	34 mins	Face-to-face
18-Aug-16	ADBA – Policy Officer	ADBA1	5 years	52 mins	Face-to-face
22-Aug-16	Farmer - Owner	FARM10	50 years	47 mins	Face-to-face
22-Aug-16	AD Plant Director	ADOP2	10 years	49 mins	Face-to-face
02-Sep-16	AD Plant Marketing Director	ADOP3	10 years	36 mins	Telephone
08-Sep-16	AD Industrial Regulator – Environmental Agency	GOV1	20 years	65 mins	Face-to-face
19-Sep-16	Senior Advisor for Waste Industry – Env. Agency	GOV2	12 years	26 mins	Telephone
23-Nov-16	Farmer – Owner and Councillor	CONS1	27 years	34 mins	Face-to-face

Figure A1: 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).

Credit Author Statement

On-Farm Anaerobic Digestion: a disaggregated analysis of the policy challenges for greater uptake

CRediT author statement

	Hafez Abdo	Rob Ackrill
Proposal Writing	√	√
Literature Review	√	√
Data Collection - Interviews	√	
Data Collection- Questionnaire	√	√
Data Collection - Workshop	√	√
Data Analysis	√	√
Writing up	√	√
Corresponding Author	√	

***Declaration of Interest Statement**

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: