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More than food or fuel. Stakeholder perceptions of anaerobic digestion and land use; a case study from the United Kingdom



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HIGHLIGHTS

- Drivers and benefits of AD are not necessarily the production of biogas or energy.
- Stakeholders perceive policy uncertainties as major challenge.
- Land use conflicts of no concern as long as AD provide agricultural solutions.
- Policies should consider synergies between energy generation and agricultural systems.

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ABSTRACT

Anaerobic digestion (AD) is of growing importance within the UK as it can make an important contribution to the countries energy and climate change targets. With the growth of the sector, discussions about competing land uses are likely to increase. For a better understanding of the synergies between agricultural land, its role and bioenergy the perception of the different stakeholders will play an important role. The perception of stakeholders related to AD, feedstock and energy crop production was investigated through interviews and a stakeholder workshop. The results indicated that from an AD operator and feedstock producer perspective, on-farm AD is more an additional activity integrated into existing agricultural systems than a renewable energy technology. The risk of a shift in agricultural practices and large areas to grow energy crops for AD is seen as low for the UK. Nonetheless, land use and related challenges need to be considered as the demand for AD feedstocks increases with the fast growth of the sector. Considering the synergies between bioenergy and agriculture as well as the motivations and benefits perceived by stakeholders will play an important role in a successful policy design to provide the required emission reduction in both sectors without subverting sustainability.

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1. Introduction

Anaerobic digestion (AD) is a technology of growing importance within the UK's bioenergy sector. AD produces two main products: biogas and digestate. Biogas can be used for heat, power and as transport fuel. Digestate can be applied to the land as organic fertiliser. With this AD is considered to contribute to the UK's energy and climate change targets and to provide several benefits such as waste management, environmental sustainability or renewable energy (Defra, 2015a; KADA, 2013). At the same time it evokes a discussion about competing land use for food or bioenergy feedstock production (ADBA, 2012; Defra, 2015a; FoE, 2014; Havlik et al., 2010; Styles et al., 2014). This is mainly the result of experiences made in countries with a large AD sector such as

Germany, France, Denmark or Italy (Defra, 2011) and experiences made with other bioenergy applications and 1st generation biofuels in relation to land use change (ADBA, 2011; Defra, 2011; FoE, 2014). The environmental and socio-economic impacts of land use change can be found in existing literature (Creutzig et al., 2015; Gawel and Ludwig, 2011; Havlik et al., 2010; Humpenöder et al., 2013; Jean Vasile et al., 2016; Searchinger et al., 2008; Van Stappen et al., 2011) and are not the main focus of this research. In the UK currently about 0.5% of the arable cropping land is used to produce purpose grown crops (PGC) for AD (NNFCC, 2015). PGC are crops grown for a single-specific use with characteristics and properties most relevant for the end-use. In the case of this research, PGC are grown as feedstocks for bioenergy (AD) applications. It is projected that the annual demand for land to produce PGC for AD will increase to about 1% of the UK's arable cropping land until 2020 (NNFCC, 2015). The AD sector and policy makers are aware of

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concerns linked to the use of PGC and land use (ADBA, 2011). However, the current risk for intensive production of a single crop as monoculture for AD is seen as low (ADBA, 2012; Defra, 2011). This is mainly due to recommendations for good agricultural practice and tariffs in place, influencing the technology pick-up and sectors' growth rate (Decc, 2014a,b,c; Defra, 2011; NNFCC, 2015). Nonetheless, the AD sector in the UK shows currently a high growth rate (IEA, 2014; Thrän et al., 2014) and little is known what role PGC will play and their land use consequences in the medium- and long-term future.

There is an increasing amount of research taking place relating to AD processes and associated technologies in the UK (BBSRC, 2016). To date little attention has been paid to the social elements related to AD facility developments, operations and the role of agricultural land. Despite an awareness of stakeholder perceptions related to growing energy crops, no research considering the social elements of PGC for AD has been undertaken in the UK. The awareness of bioenergy has been identified as lower compared to other renewables among the general public (Halder et al., 2010; Popp et al., 2009; Upham and Shackley, 2007; Upreti and van der Horst, 2004). Lack of familiarity or awareness of bioenergy projects may result in resistance, even if the projects are environmentally and economically viable and technologically robust (Halder et al., 2010; Jenssen, 2010; Mattison and Norris, 2007; Rohracher, 2010; Upham and Shackley, 2007). Public understanding and support of bioenergy is an essential element for policies aimed at the introduction and wider use of bioenergy (Rohracher, 2010). The impact and influence of stakeholders should therefore not be underestimated (Sinclair and Löfstedt, 2001; Upham and Shackley, 2006; Upreti and van der Horst, 2004). Research investigating stakeholder perception is usually done from the perspective of the public, while directly involved supply chain actors get less attention (Radics et al., 2015). This research investigated directly involved supply chain actors such as farmers, feedstock providers, AD operators, AD developers and trade organisations to identify their views on land use and general motivations, benefits, challenges of AD operations. This will add to the limited available evidence in this research area.

First, the paper gives a short overview on agricultural land use in the UK. Secondly, it will present the results from the stakeholder engagement process. The main objective was to examine the stakeholders' perception of land use and the role of agricultural land in the context of AD from a supply chain actor's perspective. The investigation of drivers, benefits and challenges for AD built an important part to understand the context and wider impacts of this specific bioenergy sector. The stakeholder engagement process presents two levels of activities. Firstly, the results from interviews with stakeholders, partly combined with site visits, are described. Based on these, a ranking exercise was conducted during a workshop with the participating stakeholders to quantify the preliminary results in an order of importance. With this, the research will provide insights into AD related stakeholder perception, which so far has not been investigated for the UK.

2. AD sector in the UK and land use implications

2.1. Purpose Grown Crops (PGC) for anaerobic digestion in the UK

In the UK about 18.5 million hectares are used as agricultural land (Defra, 2014). Fig. 1 shows that the use of this land is dominated by permanent grassland (Defra, 2014). About 27% of the agricultural land is used for crops, which makes up about 4.7 million hectares in total (Defra, 2014). This agricultural land and temporary grassland are the area, which is considered as viable in relation to land use for PGC in this research.

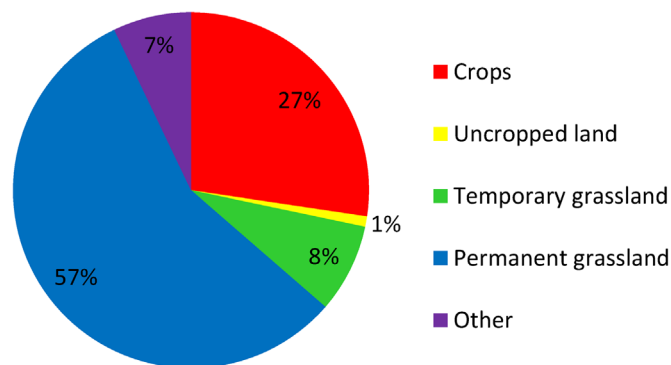


Fig. 1. Agricultural land use in the UK in 2014, generated from Defra data (Defra, 2014).

Fig. 2 shows the split of the arable crop area with wheat and barley dominating the production and maize, which is partly used as AD feedstock grown on about 4% (183,000 ha) of the crop area (Defra, 2014). Fig. 2 also shows that historically maize is not a main crop in the UK. Even though the share of area utilised for maize production is small compared to other crops such as cereals and oilseed rape, the land maize is grown on has increased steadily over the last 3 decades from 16,000 ha in 1984 to 183,000 ha in 2014 (Defra, 2014). The main share of maize grown in England is for animal feed (132,000 ha of 173,000 ha) (Defra, 2015b). There are claims that maize production for AD has little impact on changes of agricultural practices and land use in the UK (ADAS, 2016; ADBA, 2012; Defra, 2011); nevertheless, land used to grow maize for AD increased between 2014 and 2015 from 29,000 ha to 34,000 ha (Defra, 2015b).

2.2. AD Industry in the UK and Outlook

The UK's on-farm AD sector is still in development and compared to countries such as Germany or Italy relatively small (EBA, 2015). Currently 185 CE plants are operational (NNFCC, 2015). This does not include wastewater and municipal solid and commercial waste. 102 of these plants are farm-fed, and 83 are waste-fed, all totalling to a capacity of about 168 MWe (NNFCC, 2015). 18 of these plants are biomethane-to-grid plants of which 2 are industrial (brewery waste), 3 community (food waste) and 13 agricultural (8 PGC, 4 PGC-waste mix, 1 waste) facilities (NNFCC, 2015).

The mix of feedstock types and requirements of the UK's AD sector is shown in Table 1. Waste and residue feedstock are dominant with about 4 Mt while PGC make up less than one quarter (about 23% of feedstock requirements). Apart from crop residues, the feedstock requirements for all categories are projected to double by 2020 (NNFCC, 2015). This also means that the role of PGC will increase and are projected to cover about 27% of the feedstock requirements (NNFCC, 2015).

2.3. Land use change implication from the AD sector in the UK

In terms of land, currently about 0.5% of UK's total arable crop land is used for PGC for AD (NNFCC, 2015). With the increasing demand from the AD sector, the area is expected to expand to about 60,000 ha by 2020 (NNFCC, 2015). This appears to be a small amount of land used for AD crops compared to other countries such as Germany where about 1.27 Mha are utilised to grow AD feedstocks (FNR, 2015). Nonetheless, an increasing utilisation of agricultural land for PGC is taking place but the future patterns and to which extent land use is changing is unclear. Recent research evaluate the possible impact of PGC for AD (with focus on maize) and agricultural land rental prices in the UK and if this

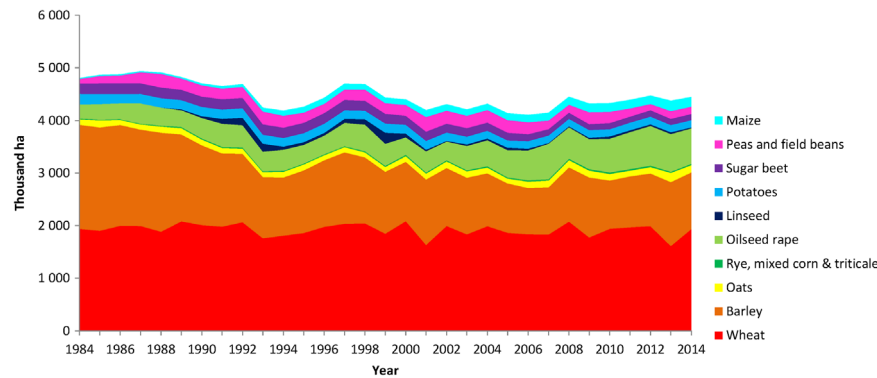


Fig. 2. Land use for arable crops in the UK 1984–2014, generated from Defra data (Defra, 2014).

Table 1

Feedstock type and requirements for AD operations in the UK (data from NNFCC (2015)).

Feedstock type	Amount per year (2015)	Amount per year by 2020 (projected)
Food waste	2 Mt	4 Mt
Manure/slurry	636,000 t	2 Mt
Crop residues	229,000 t	200,000 t
Other waste	1.2 Mt	2 Mt
PGC	1.2 Mt	3 Mt
Total	~5.3 Mt	~11.2 Mt

could result in a replacement of other cash crops such as potatoes and fodder maize or also grassland (ADAS, 2016). This research finds no statistical evidence that this currently is the case and would be in the coming years (ADAS, 2016; ADBA, 2012; Defra, 2011). Nevertheless, the AD sector and land used for PGC is small and immature within the UK and current statistical findings have to be treated therefore with caution. The land used for PGC for AD has been increasing over the last few years in the UK (Defra, 2015b) and depending on what type of crop or land use is replaced this can have significant environmental impacts such as soil erosion, nutrient loss and reduction of soil organic carbon (Palmer and Smith, 2013; Styles et al., 2014). The past development in other European countries such as Germany and Italy has shown that the AD sector and the use of PGC can lead to significant shifts in land use with negative environmental and economic impacts (ADAS, 2016; Britz and Delzeit, 2013; Delzeit et al., 2013; Steinhäusser et al., 2015). There is a high awareness regarding land use impacts among UK policy makers and the AD sector. Lessons learned from these countries and good (Decc, 2014a,b,c) agricultural practice is promoted (ADBA, 2012; Defra, 2011) as well as tariff and incentive schemes are in place to avoid the strong expansion of PGC production in the UK.

3. Stakeholder engagement methods

Stakeholders in the context of bioenergy are those affected by or can affect a decision (Radics et al., 2015; Reed, 2008). This can include a number of different individuals, companies and communities (e.g. agribusinesses, farming communities, energy generators/providers, policy makers, scientific researchers, environmental activists, regulators and local residents) (Johnson et al., 2013). Given the breadth of stakeholders involved, there are a number of potentially conflicting values and cultures, as well as different goals and decision making processes for those who may be affected by bioenergy and related technologies. Different stakeholders have different views on the environmental, economic

and social benefits of bioenergy, which in turn may influence their decision-making processes.

This research is based on stakeholder engagement processes including in the first phase unstructured interviews, which were partly combined with site visits, and in the second phase a workshop. After the interview phase, the findings were analysed and based on the preliminary results a stakeholder workshop was conducted to evaluate and scope the research findings.

Adopting multiple methods (interview, observation and stakeholder workshop), asking questions and probing nondirectively, including site visits with applying observation and reviewing existing literature and testing and reviewing the interview and workshop methods beforehand, supported managing and reducing the potential bias. Additionally, the researcher conducting the interviews, workshop and evaluating the data, is highly trained and has long-term experience of qualitative and quantitative research methods and a high awareness of the own role and influence in the research setting.

The research focused on arable farming areas in the East of the UK, where AD is increasingly taken up by farms. During the project phase from January to June 2015, six interviews with different stakeholders from the AD sector and a stakeholder scoping workshop were held. Three of the interviews were a combination of an informal dialogue and site visits, one interview was held in person during a public industry event, while the other two were telephone conversations. The interviews combined with site visits included up to four people at the same time from the same organisation but holding different roles within the enterprise (e.g., management, operation, crop production, feedstock management). In total 13 interviewees were involved in the interviews.

Interviews were chosen due to their ability to describe the meanings of the central themes in the world of the subjects (Kvale, 1996). The interviews were unstructured. The stakeholders were chosen to cover the breadth of types of stakeholders directly involved with the AD sector and operations. The stakeholders were AD operators, feedstock suppliers, farmers, AD developers, employees of an AD trade organisation and an environmental focused NGO. Some of the stakeholders took more than one role, as they were for example farmers, AD operators but also AD developers and feedstock suppliers to others. This emphasises the complexity of the stakeholder engagement process as one person might cover different perspectives and roles or sees aspects of their activities from a different, more combined and complex angle as someone just exercising one individual activity. Through the choice of stakeholders as described above and the participation of the UK's leading AD trade organisation the sample is representative for the East of the UK where AD with capacities above 500 kW per facility are increasingly established.

The interviews focused on land use aspects in the first instance. The open and informal style of the interview allowed interviewer

and interviewees to have a flexible and ad-hoc two-way conversation (Longhurst, 2009; Wilson, 2014). Leaving space for the interviewee to shape the content and subjects of the conversation provided in-depth and additional information (King, 2004; Kvale, 1996; Longhurst, 2009; Marshall and Rossman, 2006) surrounding the wider implications related to AD and the activities and perceptions of the interviewees. The interviews were not audio recorded as the majority of them took place during site visits of biogas facilities and were open multi-directional conversations. Instead, notes were taken during and detailed minutes written following the meetings (Kvale, 2007).

The data was analysed and coded according to a topic guide with any new topics emerging added when relevant and related to the research focus (Kvale, 2007). The findings were clustered into drivers, benefits, challenges and land use perception. For each cluster main categories were built, which accommodated the different factors but also presented interfaces between aspects and categories.

After the interview phase, a workshop was held with eight of the participating stakeholders, 6 of them being interviewees of the first phase but all being members of the previously involved organisations. During the workshop preliminary results from the interviews were presented and discussed with the participants. The results were presented within the clusters (drivers, benefits, challenges) but not in any specific order or ranking. After the presentation of each cluster the participants were asked to discuss and then rank the different factors according to their individual view and importance. The ranking scale was from 0 to 10 with 0 being not important and 10 very important. The workshop allowed strengthening the dialogue with and increased the communication and interaction between the stakeholders. This way perspectives and attitudes could be discovered that could not be found during individual interviews (Kok et al., 2006). The direct participation in the evaluation of the results allowed the stakeholders to exchange knowledge, influence the outcome, hence engage in the knowledge production by including their views and professional experience and expertise (Foster and Jonker, 2005; Phillipson et al., 2012).

4. Results

The results presented in this section are based on the stakeholder engagement process; both interviews and workshop. This research focused on directly involved stakeholder such as AD operators, feedstock suppliers, farmers and AD developers. The perception of the public was not the focus of the research but was to some extent covered by the involvement of an environmental focused NGO. Additionally the stakeholders were asked about their experiences from engaging with the public. There are other stakeholder groups, which were not involved in this research, such as energy communities, who operate their own AD facilities, more indirectly affected, external groups like the wider public and authorities issuing permissions or policy makers. Nonetheless, it was also of interest and investigated how for example AD operators and feedstock suppliers perceived reactions from other stakeholder groups.

4.1. Drivers and Benefits

Drivers and benefits of AD operations identified by the stakeholders involved in this project are presented in Fig. 3. For simplicity, and to avoid repetition they are presented together in one graph. Drivers and benefits are not necessarily congruent but closely linked. E.g., an additional income from AD activities or more efficiently dealing with waste can be a driver and turn out as

an intended or unintended benefit. Drivers as well as benefits could be therefore divided into the same three categories: enterprise focus, environmental focus and community focus.

The enterprise focus describes aspects based on a specific business interest and views of the stakeholder, which directly affect the enterprise or personal economic outcome. The other two categories environmental and community focus accommodate aspects with an external effect supporting and benefiting the directly involved community and wider society.

Apart from the variety of drivers and benefits, the interviews showed that various factors interact between the internal as well as external interest at the same time. E.g., the generation of bioenergy can be of an interest for the AD operator as it provides energy for the own activities, at the same time if fed into the grid it benefits the local community or even wider society by providing a renewable energy. There was also a high awareness amongst stakeholders that there are strong links between environmental and economic benefits. For example using AD to manage farm residues was perceived as economic beneficial for the own business but also as contributing to a more sustainable environment in terms of reducing landfill and emissions from decomposing biomass. Another example is producing digestate as one product of the AD operations, reducing the need for fertilisers, generating an additional income if sold or contributing to soil health and nutrient management and a reduction of emissions from not using mineral fertilisers. These interfaces make clear that there are no single or isolated motivations or benefits but the different aspects are linked to each other. The interactions between the different categories can then result in positive or negative trade-offs for other stakeholder groups creating benefits or barriers and challenges.

From the interviews, it was found that in the cases of most stakeholders being energy generation and factors related to the farm business (e.g., income generation, diversification of farm activities, managing nutrients) were highly important. This showed also from the ranking exercise during the workshop (Figs. 4 and 5).

On average, the stakeholders considered income generation as the most important driver (ranked with 8.5 out of 10 - Fig. 4). This hides that two stakeholders were thinking that income generation was unimportant and moderately important (rank 2 and 5). All stakeholders found the generation of renewable energy moderately to highly important (rank 7–10), with one stakeholder considering it less important (rank 4). This was the case where the stakeholder generates biomaterials from earlier AD process stages with a low final biogas output. Similar perceptions were found regarding energy generation as a perceived benefit. Two stakeholders considered energy generation as a less important benefit (rank 0 and 4) while the others thought of it as highly important (rank 7–10). On average, energy generation was seen as slightly less important being a benefit than a driver (Fig. 5). The stakeholder explained this with the existing incentive schemes to set up AD facilities but valued the multiple other agronomic benefits from having a running AD facility. This was confirmed by stakeholders considering income generation as a main driver to cover planning cost but once the AD facility is up and running other factors were seen as more beneficial.

Overall Fig. 4 shows that factors like waste management, emission reduction, diversification of the farm business, digestate as by-product are on average important drivers but that individual preferences and perception exist across all factors with strong or less strong variations.

In terms of importance of factors perceived as benefits the picture becomes even more scattered (Fig. 5). Depending on the farm and AD activities as well as stakeholder's roles in the sector (farmer, energy provider, trade organisation, NGO) the perception varies and while on average factors are thought of as moderately important one stakeholder might find them very important and

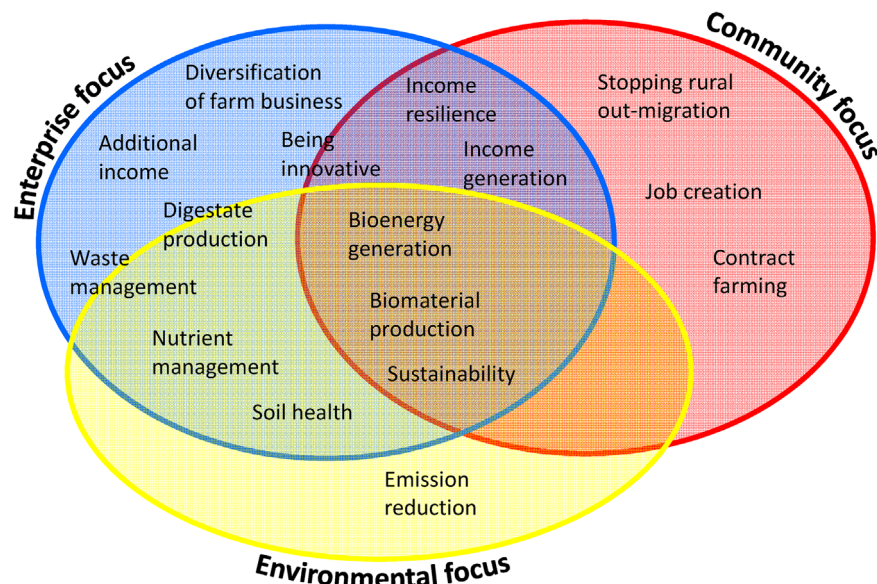


Fig. 3. Drivers and benefits perceived by stakeholders in relation to AD (empirical data from interviews).

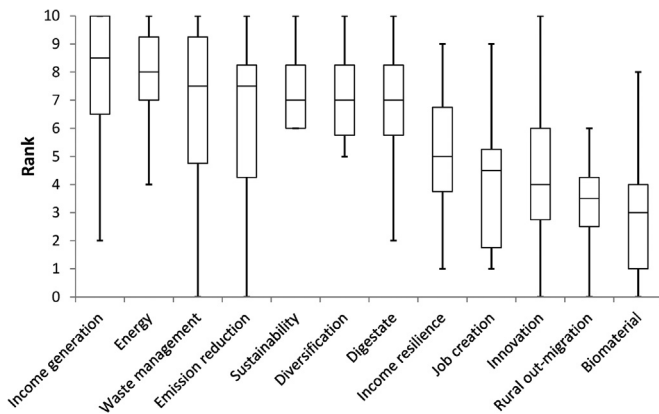


Fig. 4. Ranking of drivers perceived by stakeholders in relation to AD (empirical data from interviews).

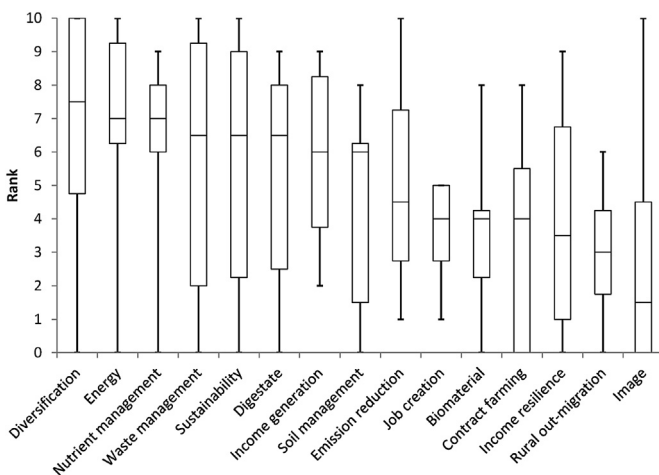


Fig. 5. Ranking of benefits perceived by stakeholders in relation to AD (empirical data from interviews).

another stakeholder might perceive them as unimportant. Overall, agronomic factors (e.g., diversification of farm activities, production of digestate and nutrient management) are ranked with a moderate to high importance by the stakeholders. On average,

diversification of the farm business through the integration of AD (both PGC and waste fed) was perceived as the most important benefit by AD operators, farmers, developers and the trade organisation (ranked 8–10 by 4 stakeholders). However, this hides the strongly divergent opinions with one stakeholder considering it as no benefit at all (rank 0) and three stakeholders considering it as a moderate benefit (rank 4–7). Nevertheless, most of the stakeholder expressed that AD is part of the existing agricultural system and its main aim is to extend agronomic activities. Even though AD is driven by the option of an additional income through the incentive schemes for generating a renewable energy, according to AD operators this integration will not take place if AD does not fit into the existing agricultural system. This becomes of particular interest when considering the public and policy perspective of AD, which mainly seen as a renewable and sustainable energy and waste management option (Defra, 2015a; Parliament, 2011).

4.2. Challenges

Fig. 6 presents the challenges related to AD operations named by the stakeholders during the interviews. Again, three categories were identified: feedstock supply and knowledge, community interface and policy and regulations. Feedstock supply and knowledge covers aspects related to feedstock properties, supply chain processes/activities and knowledge about feedstocks and processes. The community interface refers to aspects regarding the interactions between stakeholders and stakeholder groups and external impacts on the communities. The third category policy and regulations covers all kind of aspects regarding protocols, regulations, incentives along the AD supply chain.

As in the case of drivers and benefits, various factors fall into more than one category. These interfaces are processes that involve the interactions between the different aspects and stakeholders. This increases the complexity of the system and in dealing with the challenge due its wider impacts. From Fig. 6 it also becomes clear that the challenges are less of technical nature or operational processes of AD but the majority of them relate to aspects of the social and institutional framework and relationships between groups or individuals.

Fig. 7 presents the results from the ranking of the challenges during the stakeholder workshop. Even though there are large ranges in the different stakeholder perceptions of challenges, there

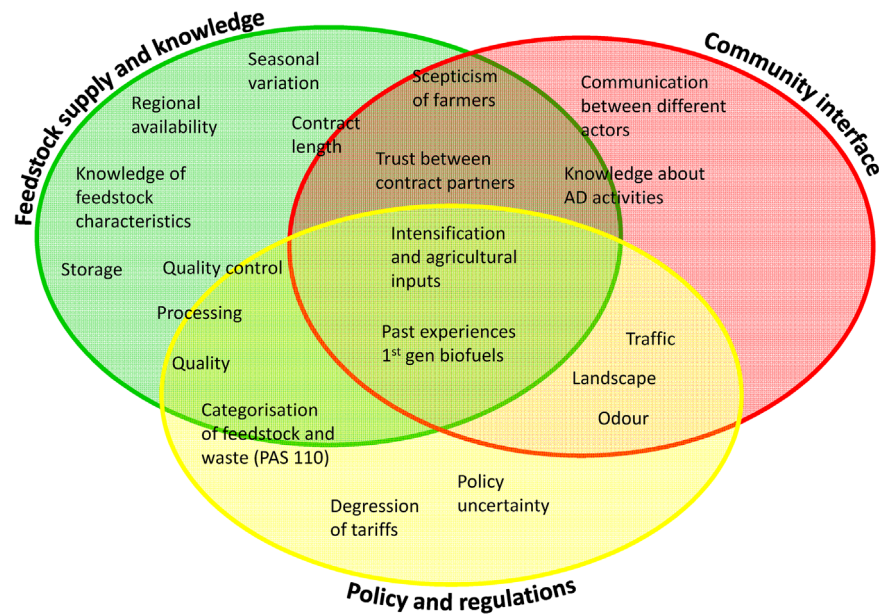


Fig. 6. Challenges perceived by stakeholders in relation to AD (empirical data from interviews).

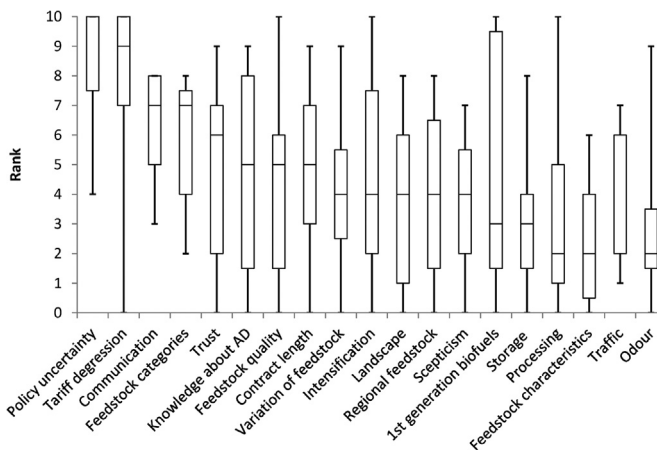


Fig. 7. Ranking of challenges by perceived by stakeholders in relation to AD (empirical data from interviews).

is consistency with perceiving policy related aspects as main challenges. Policy uncertainties and degression of tariffs were on average perceived as the major challenges for AD activities. Nevertheless, regarding policy uncertainty two stakeholder considered it as moderately important (rank 4 and 6) and in terms of tariff degression two stakeholders thought of it not important at all (rank 0) and another one thought of it as moderate important (rank 5). In both cases these were stakeholders not benefiting from incentive schemes either as they did not produce biogas as the main product or were organisations with an interest focus on environmental impacts from AD. All other stakeholders agreed that changes in policies and the degression of tariffs for renewable energy such as the Feed-in Tariff (FIT) (Decc, 2014a) and the Renewable Heat Incentive (RHI) (Decc, 2014b) create investment insecurity especially during planning.

The communication between different supply chain actors and stakeholder was identified as another important challenge. During the interviews it was flagged up repeatedly that AD operators, farmers and communities are perceived as speaking different languages. This is closely linked to existing knowledge about agricultural and AD activities. It was reported that not necessarily every stakeholder group knows what, how and why exactly

another group is doing certain activities. This can create distrust and misunderstanding and can have a negative impact on the acceptance within the community, but also for sourcing feedstocks from local farmers. This then relates to a number of other challenges such as trust between contract partners (e.g. AD operators and feedstock suppliers). Most AD operators source to some extent feedstock from outside their farm. Receiving the right quantity and quality of the right feedstock is important for undisturbed plant operations. The question of trust is in that case mutual as the AD operator relies on the quality of the delivered feedstock and the supplier on the right price and acceptance of the delivery. Even though some stakeholders did not consider these aspects important challenges, on average they were ranked as moderately important on average by the stakeholders (Fig. 7).

4.3. Perception of land use

The interviews and the stakeholder engagement activities showed that the perception of land use for AD differs between the stakeholder groups but was never seen as a single or major concern. From the perspective of AD operators integrating PGC into the farming system offers a number of agronomic benefits. Even though PGC offer higher gas and methane yields (e.g. biogas yield of maize silage 200–220 m³ t⁻¹ and cattle slurry 15–20 m³ t⁻¹ (Weiland, 2009)) and do not require permits for handling and treating waste (EnvironmentAgency, 2012), this is not necessarily the reason for using them. The stakeholder engagement process showed that for many on-farm AD operators AD is seen as part of the agricultural system as described in the above sections. Producing and using PGC is considered feasible when they fit or improve the existing farming system. The AD operators involved in this project, used PGC that were grown as breaking crop or introduced as additional crops into the existing rotation. Hence, in all cases the production of the additional PGC took place at a time when the prior agricultural practice had a period of unused land and between rotations. This is particular favourable in regions with light soils, and typical for the research area, as the additional crop contributes according to the stakeholders to the soil health in the regions which are currently affected by erosion and blackgrass and other weeds. The digestate from AD returned to the land offers then additional agronomic and environmental benefits.

Farmers participating in this project had mixed perceptions for using land for PGC. This is not driven by using land for non-food crops but by economic and risk-averse reasons. Farmers who provided feedstocks for AD only were doing so if this fit into or improved the existing production system and was at low risk. When for example maize is not a common crop in the area and would have poor yields, farmers would not grow it for the sake of producing an energy crop as the trade-offs would be unfavourable. According to the farmers, their choice of growing a crop is determined by the market and the risk connected to growing and selling the crop. This means the benefit of growing PGC must be obvious according to the stakeholders. While some farmers preferred mid- and long-term (longer than 5 years) contracts to supply AD facilities with PGC, others prefer to stay flexible in their production decision and decide season by season for what purpose and market they produce. The interviews showed when farmers see the benefits from AD operations, e.g. new markets for their products and residues and the availability of digestate, the awareness, perception and willingness of using land for PGC becomes more positive but is still linked to economic considerations. 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.

Nonetheless, there was a general awareness amongst the participating stakeholders about land use conflicts when using PGC. It appears that many AD operators and feedstock providers are conscious and favourable of good practices when using PGC and integrating AD into the existing agricultural system. Good practice is also promoted by the AD industry (ADBA, 2014). AD operators considered it also as important that the feedstocks are sourced locally as importing feedstock from further away (even just other UK regions) would be uneconomic. There were also concerns that local shortfall of feedstocks would be a problem and require sourcing from further away, making the operations inefficient. Additionally, AD operators using PGC were aware that there would be an increasing demand for energy crops in the future, which in the long-term can cause direct land use change, while indirect impacts were not considered as obvious and related to lacking knowledge and uncertainties.

5. Discussion

The aim of this research was to investigate stakeholder perceptions of AD in the UK and identify drivers, benefits and challenges related to AD to improve the understanding of the synergies between land use, the role of agricultural land and bioenergy. A large number of drivers and benefits were identified and they were perceived differently by the different stakeholders as their AD activities were based on individual, enterprise and location specific interests, preferences and views. The stakeholder engagement showed that AD related activities are not purely done for energy production but also for other motivations and benefits related to AD such as income generation, diversification of farm activities, waste and nutrient management. Even though on average main drivers and perceived benefits of AD operators could be identified (Figs. 4 and 5), not all stakeholders agreed with the average but had contrasting views.

The variety of different drivers and benefits shows the complexity of on-farm AD systems; individual stakeholders ranking the importance of these factors differently adds to this. Additionally, the interface between the different factors and activities

could be shown. This makes clear that there is none such as a single or isolated motivation or benefit but the different aspects are linked to each other. The interfaces between the different categories can then result in positive or negative trade-offs for other stakeholder groups creating benefits or barriers and challenges (Thornley, 2012; Walsh and Thornley, 2012).

AD is a fast growing sector in the UK with concerns being raised regarding the use of land for growing energy crops (ADAS, 2016; ADBA, 2012, 2014; Defra, 2011; FoE, 2014). Compared to other bioenergy sectors in the UK, AD is still relatively small and the stakeholder engagement process as well as recent literature (ADAS, 2016; ADBA, 2012; AEA, 2011) shows that land use challenges do not appear to be perceived as a major concern among the different stakeholders of this study. The stakeholder engagement process revealed as described above that the concept of AD is much more complex than just considering AD as a bioenergy option that could cause land use change as it has happened in other countries (Emmann et al., 2013; Steinhauser et al., 2015).

On-farm AD was perceived by the stakeholders as an integrational technology into the existing agricultural system. Similar results have been found by others (Tomei and Helliwell, 2015; Villamil et al., 2012) showing that bioenergy and PGC is often seen as part of the existing agricultural system. Simplifying the outcome of the decision for land being used for PGC to the concept of food-fuel interfaces does not capture the complexity of the choice and the outcome and consequences of how land is used (Tomei and Helliwell, 2015). From an AD stakeholder perspective the complexity and individuality of drivers, the fact that AD is not understood purely as a bioenergy option and that agriculture serves many more functions than producing food (Röder, 2008), raises the question if the concept of land use change and food-fuel interfaces is the right one to apply. The results of this research demonstrate that the concept of land use change does not capture the breadth of agricultural systems and related challenges, a concern already raised by Tomei (2015).

Nonetheless, in other countries the expansion of the AD sector lead to conventional farmers becoming energy farmers with different crop rotations, causing significant changes in land use (Steinhauser et al., 2015). This could currently not be found in the UK. AD operators and feedstock farmers who integrated PGC into their crop rotations experienced this as beneficial for their overall agricultural system in terms of increasing crop variety and returning valuable nutrients and organic matter in form of digestate back to the soils. Stakeholders confirmed that integrating AD into their agricultural system increased the productivities of the other crops in the rotation. Nevertheless, while policy makers and the AD sector in the UK are conscious of the potential land use conflicts from PGC (ADAS, 2016; ADBA, 2012; AEA, 2011; Defra, 2015a) recent research has shown that farmers with an improved understanding and knowledge of AD, markets as well as policy support are more likely to uptake innovations (Emmann et al., 2013; Villamil et al., 2012). With the right policy framework and market conditions a large number of UK farmers would be favourable of integrating AD into their farms (Tranter et al., 2011), which would very likely also lead to increasing production of PGC.

Policy uncertainty and degression of tariffs were identified by the stakeholders as the main challenges related to the AD sector. There is further concern that the current policies incentivise AD primarily as a bioenergy option and not necessarily support or are not complementary with what is perceived as drivers and benefits by AD stakeholders. As shown above, AD is not a stand-alone renewable energy technology but among the participating stakeholders considered as part of the agricultural system and agricultural solution. Considering the synergies between producing a renewable energy and benefits for the agricultural sector could

contribute to emission reductions and improve sustainability in both the energy and agricultural sector. While the main incentive systems for AD aim at generating bioenergy (Decc, 2014a,b) these are not solely seen as the most important benefits by stakeholders (Figs. 4 and 5). If AD is incentivised, policy would be best to focus on translating those drivers and benefits into monetary terms. If that would then be linked to e.g., the effort to increase the types of AD with the highest carbon savings, the policies which are compatible with and reflecting the main drivers and benefits such as waste management, agronomic diversification and income generation could have most likely success.

This requires sensitive incentivising in terms of supporting practices and technologies when they are feasible to the specific system. This could for example be the support of AD according to a feedstock feasible to the system and region, supporting the use and possibly trade of digestate when it reduces the application of mineral fertilisers or encouraging biodiversity and soil protection by expanding crop rotations and returning nutrients and organic matter. Including the different aspects, synergies and trade-offs of farm integrated AD considering the wider system and not just the final product could reduce some of this uncertainty perceived by the stakeholders (Purkus et al., 2015). The importance and challenges of policy uncertainties have been discussed in detail by Purkus et al. (2015) showing the importance of how policy design can regulate the balance between cost control, incentive intensity, planning security and adaptive efficiency. Considering the motivations of stakeholders into policy making could further reduce the social cost of errors (Purkus et al., 2015).

6. Conclusion and policy implication

It can be concluded that the AD sector is still developing in the UK. It remains unlikely that AD in the UK will develop into a situation similar to Germany where PGC for AD are produced in monoculture systems replacing other crops. The risk of a shift in agricultural practices and large areas to grow PGC for AD is seen as low. Nonetheless, land use and related challenges need to be considered as the demand for AD feedstock is increasing with the growth of the sector. Depending on the future development of the feedstock market for AD and the potentially increasing demand for PGC, the scope of impacts on land use will possibly require a re-consideration. This should happen in a manner that captures the breadth of agricultural systems and moves away from the single-dimensional understanding of land use towards recognising the multi-dimensions and wider functions of agricultural systems. Again, considering the synergies between bioenergy and agriculture will play an important role to provide the required emission reduction in both sectors without subverting sustainability. The motivations and benefits perceived by the directly involved stakeholders will make a significant contribution how successful such sustainability and environmental targets are and should therefore be considered in the policy design.

Considering this, the UK's AD industry needs a clear vision of their future role in the bioenergy, bioeconomy and farming sector. The AD sector's demand for PGC, and subsequent land use should not be oversimplified to a "single system". Instead, AD and related land use need to be considered within its wider context of market development, social, institutional and policy framework, specific scale and location of the given agricultural system.

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