How Should Land Be Used? Bioenergy and Responsible Innovation in Agricultural Systems

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Abstract

Bioenergy has been proposed as both a problem and a solution for land use conflicts arising at the nexus between food security and environmental conservation. But such assessments need to be considered in light of differences in the way people value the use of land and the facts that are considered or excluded in making such judgements. While technical and policy appraisals of food security favour a target-based approach that considers land as a global resource to be managed in accordance with universal targets and technological innovation for food production and nature conservation, social researchers highlight the need for a context-based approach where considerations of the role of land in people's everyday lives and its historical and cultural attachments ought to shape interventions. This Chapter highlights the assumptions and value judgements that underpin different visions of how land should be used by opening up conflicting judgements that arise when we position bioenergy in the context of current and future agricultural systems. We develop a 'responsible innovation' framework to highlight the fact that there are multiple pathways for any technological intervention. Drawing on research undertaken in the UK, we apply this framework to valuations of land use and biomass in agricultural systems. We identify a number of, often conflicting, value dimensions related to different uses of land (for food, fuel or fodder), to land quality (should marginal land be used for fuel production) and to different uses of biomass (including competition for the use of straw, the use of biomass for on-farm energy generation as opposed to national energy targets, and biomass for large-scale biorefining to meet multiple objectives at the food/fuel/environment nexus). By opening up to scrutiny the assumptions that reinforce particular innovation pathways we were able to look beyond technical innovation in agricultural systems and land use choices to consideration of social innovations that draw attention to alternative visions of land use in agricultural futures.

Introduction

Bioenergy has been positioned as both a problem and an innovative solution for land-use conflicts arising at the nexus between food security and environmental conservation (Murphy et al., 2011; Tilman et al., 2010). In this Chapter, we examine different valuations of land-use and biomass that need to be considered when assessing bioenergy interventions. Drawing on research into controversies around bioenergy, we show that at stake in this debate are different ways of conceptualizing the problem definition and innovation pathways. These arise from differences in the way people value the use of land for food, fuel or fodder, as well as in differences in the facts that are considered or excluded. Is land a global resource to be managed in accordance with universal targets and technological innovation for food production or nature conservation, or is it a place of lived experience where historical attachments, struggles and local needs ought to shape interventions? While much of the technical and policy literature on food security begins from the former position (a target-based approach), social researchers have highlighted the need to begin from the latter (a context-based approach).

In a context-based approach, we are interested in both factual and value judgments, but we want to know which facts or values are included in planning interventions and which are not, and why these choices might be important. As research and innovation systems are being charged with the responsibility to reflect on underlying values and taken-for-granted assumptions, cross-disciplinary dialogue across these perspectives is becoming more important.

From a technical perspective, the challenge arising from the global agenda for food security is commonly defined as follows - the World Resources Institute highlights that food production will need to rise by 70% by 2050 to feed a projected world population of 9.6 billion people (Searchinger et al., 2013). The problem then is whether/how such an increase can be achieved sustainably given that it is expected to require a significant intensification of agricultural activity, putting more pressure on ecosystem services which are already at risk. However, from a social research perspective, discussions of sustainable land-use need to first ask how we should *frame* the problem of food security as this will in turn determine how we think about solutions.

So, should the challenge of food security be defined simply as a challenge of increasing *total* amount of food produced at a global level with minimal environmental harm? Framing the question this way seems to lend itself to identifying new technologies of intensification as the answer. One problem with this framing is that it gives priority to technology development over social, institutional and economic factors that fundamentally affect food security. Some, therefore, reject technologies of intensification, arguing that these are being developed in a flawed socio-economic system that allows people to go hungry despite sufficient availability of food (see McDonagh, 2014 for a review). They point to how food security for some is being pursued by creating insecurity for others, for example, through agricultural ‘land grabbing’ (Borras et al., 2011) and call for developing alternative agro-ecological technologies within a farm-system prioritizing local food sovereignty as opposed to farming for volatile global markets (de Schutter, 2011).

Others highlight complexity; rather than a choice between two distinct technological systems, they emphasise multiple pathways and ways of linking technology and social objectives. For example, Jewitt and Baker (2007) note benefits from Green Revolution technologies reported by villagers in an Indian district; they agree that increasing food production was indeed valuable here, but that interventions must start from an understanding of local needs and perspectives. Harvey and Pilgrim

(2011) highlight regional variations in agricultural pathways that the language of 'global' security tends to miss.

Bioenergy provides an important case for examining the conflicts and possibilities at stake. On the one hand, it is feared that bioenergy will exacerbate pressures on food security and agricultural land. Rapid growth in first-generation biofuels over the past decade is partly held responsible for a shift towards coarse grains and oilseeds to meet competing demands for food, feed and fuel (OECD/FAO, 2015). On the other hand, bioenergy has been proposed as a solution to the challenge of reconciling food and environmental conflicts. First, energy crops are envisioned to reduce agricultural inputs, hence reducing pressure on nature. Second, energy crops grown on marginal land might be a way of reducing pressure on higher quality agricultural land. Third, there is the possibility of using biodegradable 'wastes' and residues (e.g., straw) rather than crop material for some forms of bioenergy such as biogas (from anaerobic digestion of feedstocks), biomass heat and power or lignocellulosic (second-generation) liquid biofuels for transport, again taking pressure off agricultural and high nature value land.

This chapter aims to highlight the assumptions and value judgements that underpin different visions of how land and biomass should be used, with particular reference to these visions for bioenergy. Rather than frame the discussion simply in terms of options for reducing the food security impacts of bioenergy, we open up conflicting judgments that arise when we position bioenergy in the context of agricultural systems, as they exist now and as they might in the future (Raman et al., 2015). In order to do this, we draw on the concept of responsible innovation which draws attention to the fact that there are multiple pathways for any technological interventions.

Responsible innovation in agricultural systems

The notion of responsible innovation has garnered increasing attention in recent years as research funders (e.g., Horizon 2020, Research Councils UK, Innovate UK, US National Science Foundation), industry and academia (Owen et al., 2013; Stilgoe et al., 2013) have sought to draw attention to the social and value dimensions of the processes and products of research and innovation. Responsible innovation builds on a continuum of technology assessment (TA) methods including constructive TA (Schot and Rip, 1997) and real-time TA (Guston and Sarewitz, 2002) as well as deliberative democratic methods such as upstream engagement (Wilsdon and Willis, 2004), but further aims to stimulate reflection on what innovation *should* do in response to pluralistic societal values and visions for future development.

Looking at agricultural systems through the lens of responsible innovation enables us to draw attention to how land and biomass *should* be used to address the societal challenges at the food/fuel/environmental nexus. Asking how land and biomass should be used in light of research and innovation (such as in agricultural production methods, pesticides, harvesting technologies, transport and logistics, physical infrastructure) and economic growth addresses issues of technical innovation. Although technical innovation and economic efficiency in agricultural systems are vital, there is a need for a wider **systems perspective** as innovations are also socially (as well as culturally and territorially) embedded (Fløysand and Jacobsen, 2011). It is important to evaluate the social impact of innovations as there are generally winners and losers in terms of the **distribution of impacts**. Addressing issues of social innovation in agricultural systems is also necessary to help mitigate the uneven distribution of impacts by exploring value-based questions. Who decides how land and biomass should be used? Which communities/regions have borne the negative impacts, which ones benefitted? What alternative ways might there be of using and managing land to enable a more equitable distribution of impacts? Attending to such matters is important as the issues at stake are more often linked to people's values and beliefs about what agriculture is and how it should progress rather than about what is technologically feasible (Thompson, 2012). Social innovation can assist progress by facilitating change in the existing evaluative, institutional, cultural, and regulatory structures of agriculture systems so that, for example, new land use management practices may evolve, new supply chains may be established and existing institutions may innovate to better inform land use decision-making.

Applying a responsible innovation framework allows us to open up the values and assumptions about land use on which present-day agricultural systems are based and to ask if there are other ways of conceptualising agricultural futures. By making explicit the value judgements involved in selecting one pathway over another, a responsible innovation framework opens up the possibility of looking beyond technical innovation in agricultural systems and land use choices to consideration of social innovations that draw attention to **alternative visions** of land use in agricultural futures.

To apply the responsible innovation framework to valuations of land use and biomass in agricultural systems, we adopt the above approach to identify key value dimensions related to a selection of different uses of land and biomass as well as alternative visions of agricultural futures. We draw on research undertaken in the UK and situate it in the global agricultural complex.

Valuations of land use

Food, Fuel and Fodder

Bioenergy draws attention to the value question of how we ought to prioritize different purposes for which land may be farmed or conserved. Controversy around the use of food crops such as maize, sugarcane, grains and vegetable oils for liquid transport biofuels has been widely interpreted in terms of a food *versus* fuel divide, with land-use for food assumed to have higher value over fuel (Mohr and Raman, 2013; Pimentel et al., 2009). Non-food bioenergy feedstocks (dedicated energy crops such as miscanthus and SRC willow; agricultural and forestry residues or co-products such as wheat straw), are, therefore, assumed to avoid conflicts with food security and other non-agricultural land uses. But as we show below, this target-based assessment is too simplistic.

First, using non-food feedstocks does not in itself avert a food-versus-fuel conflict. It only appears to do so if we frame the intervention in terms of overall targets, in this case, of biomass feedstocks and their energy value for liquid fuel, or biomass combustion for heat and power. From a context-based perspective, food-security concerns remain if non-food energy crops were grown on land having some value for food production (Mohr and Raman, 2013). This has added significance for dedicated energy crops should these be grown for fuel used by wealthier groups, on land of subsistence value for vulnerable populations in the global South. Food-versus-fuel in this respect is partly a matter of *whose* fuel needs are met and whose needs (for food and fuel) are compromised in the process (Raman and Mohr, 2013).

Second, the fact that fuel and food are inter-related systems (Karp and Richter 2011) complicates the valuation of land for producing food separately from fuel. For subsistence farmers, land provides a source of food as well as fuel, for example, in the form of fuelwood and animal dung. Removing animal dung and crop residues from the field for domestic energy use, rather than using these materials to improve soil health may have negative implications for future agricultural production. In industrial agricultural systems, crop cultivation relies on the use of fuel for fertilizer, machinery, distribution of inputs and outputs, etc. Energy footprints are now assessed alongside water use, biodiversity, pollution and other impacts in environmental assessments of agriculture (Khan and Hanjra, 2009), hence, technologies to reduce the energy footprint of food production would be of value. But this is also where value judgments clash over whether to perpetuate industrial agriculture, promote alternative methods or develop a 'third' way drawing on both industrial and alternative techniques in order to meet food and environmental objectives.

Third, the valuation implied by food-versus-fuel can be reframed in terms of *meat*-versus-fuel (de Fraiture et al 2008). As grain is not just consumed directly by humans but is also fed first to livestock, the question of whether all 'food' crops should be valued equally is being opened up. Some now advocate biofuels on the basis of reductions in the use of land (and products of land including grain and wheat straw) for animal feed, a point prefigured in an early assessment of bioenergy by David O. Hall (1991) and echoed in some recent stakeholder assessments (CAT, 2010; Carbon Cycles and Sinks Network, 2011). In other words, the concern about food versus fuel (where food is given moral priority) has been reframed in terms of a particular kind of food (meat) versus fuel (where fuel is given priority).

A recent study found that the meat versus fuel framing was widely used by key stakeholders in the bioenergy sector in Denmark (Shortall, 2014). The dominance of the pig production industry and export market in Denmark may explain why this argument was particularly prevalent, and why pig meat was framed as an environmentally damaging, luxury product for export that compared unfavourably with energy crop production which was seen to be an environmentally benign or beneficial necessity for local consumption. Here, a very clear value distinction is being made between food and fodder whereby fodder for animal production is not food and as such there is no value conflict if fodder production was to be displaced by energy production. The reframing of meat as an excessive luxury in the context of a resource-challenged future problematizes the food-versus-fuel valuation by highlighting the fact that not all food sources are valued equally and there are other important factors at play in considerations of the best use of land (Wassenaar and Kay, 2008). The OECD/FAO (2015) projections in Figure 1 lends weight to this contention. In land-use terms, agricultural land (defined as arable land and permanent crops and pastures) accounts for around 38 percent of global land area, of which about 12 percent is used for crop production (FAO, 2012). Cereal production dominates the crop sector and continues to be the most important food source for human consumption. However, increasing affluence and urbanisation, particularly in developing regions, are causing diets to shift towards animal-based products, such as meat, milk and dairy, which use land not only for grazing but also feed production. While global cereal consumption is expected to expand by almost 390 Mt by 2024, the production of coarse grains, used primarily for animal feed and (first-generation) biofuels (Figure 1), is predicted to constitute more than half of this increase (OECD/FAO, 2015). This reflects the fact that livestock production is now the world's largest agricultural land use sector and livestock consume around 60 percent of the global biomass harvest (Weindl et al., 2015).

<FIGURE 1 HERE>

These figures have been used to make a case for intensifying the existing global-industrial agricultural system so as to meet (and continue to meet) rising demand. But another vision is predicated on the argument that this global agri-food economy does not meet the needs of the poor and the vulnerable and indeed, that it has led to the exploitation of subsistence farmers and small-holders; what is required is a different system based on local sovereignty and agro-ecological techniques (de Schutter, 2011). These different value-judgements need to be considered in discussing which interventions to adopt.

Use of Marginal land for Fuel

While the food-fuel-fodder debate is about the proper use of arable land, a further complication arises when we consider so-called marginal land. Using marginal land to cultivate energy crops has been proposed as a way to meet fuel needs without compromising food security (Renewable Fuels Agency, 2008) or even biodiversity (Karp et al., 2009). But what counts as marginal land – or what is variously characterised as idle, degraded, under-used or under-utilised land - remains ambiguous (Shortall, 2013). As we show here, this is in part due to different ways of valuing land quality and the implications for land-use – or, indeed, if, when and/or by whom land should be used for cultivation or left in a natural state. Also important is the extent to which factual assumptions - about how much marginal land is available and where, and how much such land can yield – hold up to scrutiny. Again, we need to look beyond overall targets and attend to context.

In the UK, a domestic bioenergy system has been proposed as an option where marginal land within the country would be used to cultivate energy crops. But a recent review of academic, consultancy, NGO, government and industry documents shows that ‘marginal land’ does not have a consistent meaning or valuation (Shortall, 2013). In the early 2000s, perennial energy crops such as willow were regarded as marginal crops and as such, relegated to the least productive ‘marginal’ land where yields were lowest (Royal Commission on Environmental Pollution, 2004). Once food-based biofuels became controversial, marginal land and perennial crops came to be valued more highly as a way of promoting bioenergy without consequences for food security. But to distinguish marginal land, we need more than generic definitions.

One meaning of marginal land within the UK refers to land judged ‘unsuited’ for food production while a second refers to land of ‘lower quality’ where food crop cultivation would be less productive though not impossible (Shortall, 2013). The standard Agricultural Land Classification (ALC) system is the typical reference point where Grade 1 land is defined as excellent for arable purposes while grade 5 is very poor. In theory then, energy crops on grade 5 land might pose no conflict with a high value placed on land for food, while grades 4 and 3 might pose some conflict but one that is judged to be worthwhile if both fuel and food needs must be met. In practice, however, interventions will need to consider how valuations play out in the context of a specific place. The culture endemic to a specific place strongly determines values related to the natural environment and how land should be used and are likely to vary not only among different users of land but also between local communities and visitors who each experience a different sense of place (Slee et al., 2014).

First, ALC classifications may or may not correspond with farmers’ judgments on the viability of using parts of their land for bioenergy. Second, the value of using land for bioenergy will need to be compared with values associated with previous uses. In some places, it may benefit biodiversity (for example, perennial crops grown on contaminated land) whereas in others, it may not (for example, converting land designated as ‘set-aside’ for environmental purposes in the former European Commission scheme). Third, it is not clear if perennial crops can be profitably grown on lower quality land on the large scale that is envisioned in energy targets. This has also been a matter of concern for those looking beyond the UK with some environmental NGOs questioning if energy crop production would be economically-feasible on lower quality land and whether production would be limited to this type of land alone (The Gaia Foundation et al., 2008). But if we do assume that some lower-quality land can/will be used, we need to keep in mind that environmental gains may be offset by the process of making degraded land viable for large-scale production - notably, some lignocellulosic crops have needed additional irrigation (Ribeiro and Quintanilla 2014; Jewitt and Raman, in press).

Fourth, and related to the previous point, if energy crops do become financially attractive, it may not be possible to restrict cultivation to land that is judged to be marginal in terms of viability for food. How the market values land is, therefore, a key issue. Another meaning of marginal land in bioenergy discussions is based on market logic (Shortall, 2013). 'Economically marginal land' refers to land where energy crop production is *likely* to take place for economic reasons (Committee on Climate Change, 2011). But this then opens up the question of how market valuations relate to or diverge from social and environmental valuations, and/or from those of people living on land designated as marginal.

These conflicts in valuation of land become more acute when we turn to options proposed for bioenergy at a global level with land in various parts of the global South identified in bioenergy potential maps as 'marginal' or degraded. The idea that energy crops can provide farmers with additional income over and above food production is appealing (Schubert et al., 2008), but some have contested the idea of marginal land, asking whether it exists in sufficient quantities and observing that apparently marginal land may have existing value for subsistence (Franco et al., 2010) environmental and nature protection purposes (Borras & Franco, 2010). Experience from history and other national developments of bioenergy show that policy or expert designations of 'wastelands' have periodically clashed with the experience of people relying on such places for their livelihood (Brara, 1992; Jewitt and Raman, in press).

In sum, proposals for using marginal land for bioenergy rely on the assumption that such land has no or little (current) value, and that it can be productively transformed for meeting fuel needs without compromising food security. It is assumed that this can be done without negative environmental consequences and indeed, that impacts of perennial crops on some aspects such as biodiversity can actually be positive. Not only do these assumptions need to be tested against alternative expectations and valuations as discussed above, they also need to be assessed in light of future impacts of climate change on land uses. In Scotland, land use classifications have already begun to evolve to reflect that the 'squeezed middle' (the classes of land that comprise intermediate quality farmland) is becoming more dynamic as land previously considered to be of prime quality or poor quality changes as a consequence of climate change (Slee et al, 2014).

Valuations of biomass use

In addition to differences in how land might be valued, priorities for biomass also vary. What then are the best uses of biomass? In this section we explore this question with reference to competition for the use of straw, the use of biomass for on-farm energy generation as opposed to national energy targets, and biomass for large-scale biorefining to produce multiple value-added products.

Agricultural Residues: The case of straw

The term, agricultural residues, refers to a range of co-products of crop production, notably, seed husks and straw. Straw, the more abundant of the two, is a potential feedstock for bioenergy. Cultivation of the most widely produced crops in the world, wheat, rice, barley, maize, rye, oats and millet, (FAO, 2015), all result in straw production to varying degrees, suggesting a sizable resource across countries in both the global North and South. In technical and policy visions for bioenergy, straw is valued as a means of overcoming land-use controversies through utilising material produced from existing annual crop production methods; similar valuations are also evident in some NGO literature (e.g., CAT, 2010). But, contextual aspects of valuation remain important as we now show, drawing on literature on a range of different straws and a UK-based wheat straw case study.

Straw may be burned, incorporated into the soil or baled for subsequent uses, depending on the farming system in question. Each of these practices is informed by implicit or explicit valuations which are shaped by statutory regulation (or lack of it), management needs and traditions, farmer preferences, and feasibility, and which may also come into conflict (Agriculture & Horticulture Development Board, 2014).

Burning of straw is widely practiced globally as a cheap and quick way of clearing fields, and provides non-chemical means for destroying weed seeds and pests such as slugs, reducing disease in the following crop and returning some nutrients to the soil in the ash (Williams et al., 2013). However, burning of straw is a major source of air pollution, releasing carbon dioxide, carbon monoxide, nitrogen and sulphur oxides, particulate matter (Gadde, et al., 2009) and also carcinogenic dioxins (Gullett & Touati, 2003; Korenaga & Huang, 2001) that increase the risk of respiratory disease (Gadde, et al., 2009; Tipayarom & Oanh, 2007). Therefore, as an alternative means of handling straw, bioenergy may be valued as a way of improving health while creating alternative income streams for farmers.

Yet, in an agricultural system in a poor rural region, capacity to process straw for bioenergy may be limited as Shuping (2009) notes in the case of China. Baling or incorporation requires labour intensive practices, or energy intensive technologies that are difficult for poor rural farmers who have limited access to capital, fuel and machinery. In this context, changing straw-burning practices requires more than placing a high-value on long-term health outcomes or energy outputs; a more holistic approach is needed.

In the UK, infrastructures, machinery, knowledge and markets have developed to facilitate widespread straw baling and trade or incorporation. While environmental health standards led to a statutory ban on burning straw in 1989, straw is valued highly for a range of other purposes, making availability for bioenergy a challenge. First, a large proportion of straw in the UK is incorporated directly into the soil to boost organic matter and nutrients to maintain soil fertility for arable farming (Committee on Climate Change, 2011). Where crop residues are routinely removed, this has been seen to cause negative environmental impacts on soil health and biodiversity (Franzluebbers, 2002; Wilhelm et al., 2004; Lal, 2005). The culture of incorporating crop residues into soil is widely practiced in organic agriculture to maintain soil in the absence of inorganic fertilisers with the aim of making agriculture self-sufficient in nutrients and energy (Jørgensen, 2007). In industrial farming, the high price of Nitrogen and Phosphorus fertilisers creates high value for incorporating straw as a means to reduce costs, and agronomists promote it for this reason.

Second, straw is widely baled and sold onto market or used within mixed farming systems. Straw is sold principally to livestock farmers for bedding and silage, but also for carrot production, mushroom compost, and equine and small animal bedding. Beyond the agricultural sector, straw has further competing uses such as for cooking fuel, basketry/crafts, packaging and construction. These competing market valuations may pose constraints on supply through price conditions that mean it is uncompetitive as a feedstock in energy markets.

This picture of standard practice is complicated by a high level of supply and demand uncertainties in UK straw availability in any period. One key factor in the UK is the prevailing weather during the harvest which determines how willing arable farmers are to bale the straw. Wet weather encourages incorporation and quick establishment of the following crop to reduce soil structure damage. The prevailing weather during the winter months also dictates the extent to which livestock farmers may need to purchase straw as mild weather enables longer outdoor grazing, therefore, reducing demand for straw, whereas a late and wet spring increases demand as the animals must remain inside. Livestock farmers have often needed to buy straw on an *ad hoc* basis from straw merchants. However, the diversification of bedding materials now available to livestock farmers (sand, sawdust, paper waste) means that demand for straw from this sector may continue to decline, creating opportunities for other purchasers.

Uncertainty also arises from international market valuations. In the UK inter-regional trade in straw between arable and livestock regions is common, but this also includes international trade (see Agriculture & Horticulture Development Board, 2015 for export figures), which may be volatile. Bad weather on the continent and in Ireland means that occasionally farmers from Spain, Germany, Netherlands, France and Ireland access the UK straw market to make up any shortfall. International buyers are often willing to pay high prices to secure the straw they need, warping local markets. It is within this unpredictable and potentially rapidly changing context that bioenergy users are attempting to establish a constant and regular supply of straw.

Finally, straw availability is also influenced by how the value of efficiency is shaping other innovations whose unintended consequence is reduced straw production. In the UK, continued up-scaling of combine harvesters suited to large-scale monoculture production has meant a reduced amount of combine header control in uneven fields, meaning more straw is left behind in the stubble. Crop breeding has consistently boosted seed yields at the expense of straw yields with modern varieties being sometimes significantly shorter than their predecessors. In a global context, mechanisation of agriculture, which is an important component for expanding straw use as a baled product, reduces labour and, therefore, employment opportunities, and intensifies production methods. In the future, adoption of modern crop varieties may, therefore, change what now appears as a significant straw surplus.

Organic Wastes

Anaerobic digestion (AD) of organic waste generates biogas which can be used for a range of energy needs (see Figure 2). In terms of the challenge of producing food and fuel with minimal environmental harm, AD appears to be an ideal solution as it relies on food and plant waste and slurries and sewage rather than crop material. However, as AD has come to be valued more highly for optimal energy outputs, contradictions are emerging with strategies such as the UK's Anaerobic Digestion Strategy and Action Plan (DEFRA 2011) implicitly incentivising new feedstocks other than 'waste' alone. This section draws on a case study of historical change in the UK's AD sector.

Farming is energy intensive and the value of an environmentally friendly farm or farming community, self-sufficient in energy, has been revived in recent years (Royal Agricultural Society of England, 2014). In the UK, farm-level AD emerged in the 1970s as a promising multi-functional technology for farmers needing to find sustainable ways of managing wet wastes while also meeting some of their energy needs (heating farm buildings, stoves, etc). This option flourished at a niche level in a policy regime that supported farm-pollution abatement measures.

<FIGURE 2 HERE>

As energy output became a value in itself, AD has been recently promoted more heavily in UK policy but at the expense of transforming the vision of self-sufficiency. Incentives for using biogas as an off-grid alternative to fossil-fuel heating on the farm are fewer as maximising energy output has meant AD being valued more for electricity generation and heat-and-power (CHP). This means investing in new materials such as equipment to connect to the grid (Reno, 2011) and/or looking for added feedstocks beyond slurry waste. Studies have highlighted that dry material to the tune of at least 30 percent improves the efficiency of conversion of wet wastes from farms (which are low in energy density) and maximises biogas yields (NNFCC 2011). This has facilitated a shift away from incentivising smaller, predominantly slurry/manure-fed farm-based AD units to larger plants located beyond the farm that co-digest multiple materials including slurry, food waste, vegetable wastes and crop residues. Increasingly purpose-grown energy crops such as maize and wheat are also promoted to boost biogas yields (Redman, 2008; Jones and Salter, 2013).

Energy crops have been key to the rise of the German AD sector where Britz and Delzeit (2013: 1268) suggest that the increased use of fodder maize as an AD feedstock has potential to cause "sizeable impacts on global agricultural markets in prices and quantities, causing significant land use change outside of Germany" while "subsidies for biogas production are passed on to electricity consumers". In the UK, the use of maize for AD plants has been criticized for the fact that it is harvested late in the year and leaves fields susceptible to erosion from surface run-off – especially in south western England where rainfall is high and often occurs in intense episodes (Palmer and Smith, 2013). In dairy farming systems where maize is used as both a fodder crop and as an AD feedstock, pollution problems are common, especially in nitrate vulnerable zones. This stems from the fact that farmers struggle to contain their digestate until the start of the spreading window in mid-January and risk damaging the land and causing high levels of nutrient rich runoff by getting digestate back onto the land in inappropriate conditions. These problems can be compounded by compaction damage which leads to the rapid runoff of rainfall into watercourses instead of infiltration into the soil (Palmer and Smith, 2013: 573).

However, in the case of grass as opposed to purpose-grown maize, a more positive case for dry material (not strictly, 'waste') for AD is being made in light of value for biodiversity and aesthetics in addition to energy per se. Grass-based biogas production is promoted by the Danish government to help meet renewable energy targets while providing environmental benefits (Ministry of Food, Agriculture and Fisheries of Denmark, 2008). Land under grass cultivation contains high levels of soil carbon and houses biodiversity associated with open landscapes which is needed to fulfil Denmark's commitments under the Convention on Biological Diversity (Det Økologiske Råd, 2010). Because grass production can be less intensive than arable production, some have suggested grass for energy use as a beneficial use of environmentally sensitive land otherwise susceptible to nitrogen leaching and long term damage if used intensively (Ministry of Food, Agriculture and Fisheries of Denmark, 2008). Grass is also seen to have an aesthetic advantage over tall-growing energy crops such as willow or miscanthaus, whereby the former is considered a 'natural' part of the landscape and the latter as potentially invasive species (Shortall, 2014).

Comparing the valuation of grass with perennial energy crops (willow), we also see a growing case for valuing flexibility. Once planted, perennial crops stay in the ground for 20-30 years, whereas grass can be established quickly thus enabling it to be part of a crop rotation system. The issue of crop flexibility and being able to reverse cropping decisions is valued in small-scale farming as reported in a multinational study conducted by Ribeiro and Quintanilla (2014) who noted that some energy crops were harder to dislodge because of their root architecture and depth and because energy crop supply chains are fundamentally different to those of food crops. Swapping between the two production systems thus involves considerable risks beyond just that of investment of time and money.

The biorefinery concept

The biorefinery concept (Figure 3) introduces a potentially novel way of valuing biomass-use to meet multiple objectives at the food/fuel/environment nexus. But as we see here, the feasibility of the technology has been questioned, and alternative ways of envisioning multi-functional agriculture have been put forward.

Biorefining involves the processing of biomass into different products such as plastics, chemicals and building materials in the same way that crude oil is processed and refined into more useful oil-based fuels (Taylor, 2008). The concept was promoted in the EU's 2020 bioeconomy strategy as the application of biotechnology innovations to ensure the sustainable use of resources, whilst ensuring competitiveness and fostering innovation in Europe (European Commission, 2012). It aims to safeguard food and energy security whilst overcoming resource constraints, dependence on non-renewable resources and tackling climate change. Because biomass can be processed in the biorefinery into many different products, here the food versus fuel conflict is reframed as a win-win process that produces food *and* fuel (Zhang, 2013). In this context, biomass is positioned as the fossil fuel of the future that can be decomposed and recomposed to produce the same products as in an oil refinery (Gylling et al., 2012). In this way, the distinction between food and fuel crops is no longer seen as the most important way to value crops, rather crops will be produced because of their efficiency in using nutrients and other resources, their environmental benefits and their suitability for processing into multiple products in the biorefinery (Levidow et al., 2013).

<FIGURE 3 HERE>

However, some question the idea that biomass can be readily substituted for fossil fuels: i.e. that plants are the oil of the future. As highlighted above, use of land for biomass production necessarily involves resource trade-offs with food production and environmental services, which cannot be easily overcome by strategies such as using marginal land or crop residues. In addition some point out that there are important chemical differences between biomass and fossil fuels as an energy source (Canakci & Sanli, 2008; Miller and Tillman, 2008). Moreover biomass is significantly less energy dense: fossil fuels are biomass that have been condensed in the ground for millions of years, whereas biomass converts 'real time' solar energy to fuel (Pimentel, 2003). Photosynthesis is seen as a relatively inefficient way of converting solar energy to useable energy for human societies (Zhang, 2013). Thus, some argue that biomass cannot straightforwardly substitute fossil fuels in energy generation, a situation further compounded by the high energy demands of industrial societies that have been built up around energy dense, relatively abundant fossil fuels (Shortall et al., 2015).

In sum, the question of what should land be used for raises the question of how we should develop bioenergy if we are to transition away from fossil-fuel economies. Should we think of bioenergy as a substitute for maintaining life as it currently organised and as implied in many technical and policy visions? Or should a decrease in overall energy use be at the core of a future bioenergy alternative to fossil-fuel systems? (CAT, 2010). These questions imply fundamentally different values.

Conclusions: the responsible innovation of agricultural futures

A quarter of a century ago, bioenergy pioneer David O Hall (1991) presciently observed the need for a realistic assessment of food versus fuel arguments against the background of rising food surpluses in some parts of the world and food and fuel shortages in others, linked to increases in the production of animal feed and the potential for agricultural productivity. Where biomass energy projects have failed, Hall (1991: 733) claimed this had been due to a technocratic approach which first prioritises the need for energy rather than a 'multi-uses' approach which asks "how land can best be used for sustainable development”. Although its use as a formal tool for democratic governance did not exist back then, Hall was in essence advocating a responsible innovation approach to agriculture to take into account the reality of food and fuel challenges and to evolve efficient methods of utilising available land to produce food and fuel, besides the other products and benefits of biomass.

One of the aims of responsible innovation is to open up to scrutiny the assumptions that reinforce particular innovation pathways and explore alternative visions before technological commitments become entrenched. This Chapter has contributed to this by asking how should land be valued, used and managed in the wider context of envisioning agricultural futures able to meet the needs of a burgeoning global population under challenging climactic conditions with minimum losses to stored carbon and biodiversity. A societal grand challenge such as this requires new ways of innovating beyond the usual ‘techno-fixes’ to make the best and most efficient use of land and biomass.

Social innovation is not captured or considered in efforts to model agricultural futures, such as those underpinning the scenarios used in OECD-FAO Agricultural Outlook reports (which are based on specific assumptions regarding macroeconomic conditions, agriculture and trade policy settings, weather conditions, longer term productivity trends, and international market developments (OECD-FAO, 2015), all of which reinforce technical innovation) and which tend to conceptualise agriculture as a singular bioeconomic activity either in terms of individual countries or as a global complex. Only when you take a more socially, culturally or territorially sensitive approach to assessing agricultural futures do issues signalling the need for social innovation, such as mitigating the uneven distribution of agricultural impacts, come to the surface.

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