AC0410 ANNEX 3: ECOSYSTEM SERVICES ASSESSMENT

(Jens Dauber and Barbara Urban)

1. Background

The demands on provisioning ecosystem services from farmland will further increase in coming decades as greater amounts of agricultural products will be required, including food, fuel and materials. Increased production may however well compete with the delivery of other ecosystem services from agricultural land (Firbank et al. 2013). Bioenergy is an important part of the UK Government's plans to meet the Renewable Energy Directive objectives in 2020 and the low carbon objectives by 2050 (DECC 2012). The extended cultivation of energy crops can lead to conflicts because they compete for land with food production, and they have various ecological, economic and social impacts (Lupp et al. 2011). There is growing recognition that bioenergy systems are associated with risks and uncertainties on a range of ecosystem services on groundwater, soils, biodiversity and the overall appearance of the landscape scenery in the locality where they are deployed (Lupp et al. 2011, DECC 2012, Howard et al. 2012). The cultivation of energy crops can have social and environmental net benefits but this depends on the contribution of the bioenergy systems to land-use change and direct impacts for producing the feedstock (Obersteiner et al. 2010). The challenge is to optimize agriculture, including bioenergy feedstock production, in a way that multiple ecosystem services are delivered simultaneously. There are however agronomic and environmental constraints to multiple ecosystem service delivery and improving our understanding and quantifying those constraints is vital for developing management strategies for supporting human well-being (Maskell et al. 2013).

The UK Government has made a commitment to increase the energy from waste produced through anaerobic digestion (AD; Defra 2012a). Biogas produced from AD is generally regarded as very sustainable with respect to GHG savings because it can be used directly for heating and electricity generation and as a substitute for other fossil fuel applications (Boulamanti et al. 2013). Its importance for mitigation of climate change, however, is strongly dependent on the choice of feedstock and operational practices (Boulamanti et al. 2013). Agricultural residues and food wastes are preferred feedstock for AD in the UK but supplementary use of purpose grown crops (e.g. maize or grass silage) is under consideration because they improve the operational efficiency of the AD process and benefit farm-based AD systems by extending the season during the summer months, when animal manures or slurries are not available (AEA/ADAS 2011). As with other bioenergy feedstock, there are general concerns about the sustainability of purpose grown crops for AD, particularly with respect to land use and biodiversity (AEA/ADAS 2011).

Objectives

The aim of the present ecosystem service (ES) assessment is to complement the LCA assessment of the environmental consequences of various anaerobic digestion (AD) and bioenergy options. The focus of the ES assessment is on consequences of farm-scale land-use changes. Ecosystem service delivery of baseline reference farm systems (i.e.: a large dairy farm and an average dairy farm in southwest England and a large arable farm in east England) is compared to scenarios for farm scale biomass production from Miscanthus and AD biogas production from grass and maize, and biodiesel production from oil seed rape. Pertinent ecosystem service impacts are identified and reported for the main scenarios using a traffic light system.

2. Methods

All baseline farm types comprise enclosed farmland in the UK, following the definition by Howard et al. (2003). Enclosed farmland is managed primarily for the provisioning of food but is important for many other ecosystem services as well (Firbank et al. 2013). For the assessment of ecosystem services (ES) delivered by the baseline farms and the respective AD scenarios (see AC0410 ANNEX 1 for a detailed description of the baseline farms and AD scenarios), we follow the ES classification developed in the UK NEA (see Table 2.2 in Mace et al. 2011). In the UK NEA, 'ecosystem services' are defined as the outputs of ecosystems from which people derive benefits (Mace et al. 2011). They are considered under the broad headings of provisioning, supporting, regulating and cultural services (Mace et al. 2011). We primarily focus on final ES (i.e. ES which directly contribute to the good(s) that are valued by people and for whose delivery people intervene or manage ecosystems; Mace et al. 2011) with high importance for enclosed farmland (Firbank et al. 2011). Those final services accounted for comprise provisioning, regulating and cultural services. Supporting services are always intermediate services or processes according to Mace et al. (2011) and were not taken into consideration here. It has to be noted, however, that the ES classification of the UK NEA is inconsistent and varies among chapters of the technical report and follow-on publications (e.g. Mace et al. 2011, Firbank et al. 2011 and Firbank et al. 2013). We therefore developed our own interpretation of the classification and characterization of ES which we deemed to be most relevant for the assessment of the AD scenarios (Table 1).

Table 1: **List and characterizations of ecosystem services (ES) which were identified as most relevant for the ES assessment of the AD scenarios. ES classification is based on the UK NEA (Mace et al. 2011, Firbank et al. 2011)**

1. Provisioning services	
1.1 Food	The majority of parcels of Enclosed Farmland are managed primarily for the provisioning of food for human consumption (Firbank et al. 2011). In this category only direct provisioning of food from crops is included.
1.2 Fodder	Provisioning of feed for livestock and thus indirect provisioning of food for human consumption. Both ES 1.1 and ES 1.2 are met by the removal of net primary production and the manipulation of nutrient cycles (Firbank et al. 2011).
1.3 Biomass for energy	Provisioning of feedstock for heat and bioenergy generation and for transport biofuels.
1.4 Water supply	The service of groundwater recharge and recovery of aquifers is balanced against the disservice of water abstraction by crops and land management (e.g. irrigation).
1.5 Wild species diversity	Provisioning of species that are valued as food (e.g. wild fruit, mushrooms, game species) or for medicinal values. Provisioning of genetic resources for crop and livestock breeding, pharmaceuticals and bioprospecting.
1.6 Carbon sequestration	The service of carbon sequestration or storage in soil is balanced against the disservice of carbon depletion.
2. Regulating services	

2.1 Hazard regulation	Here we focus on the regulation of soil erosion by wind and water.
2.2 Regulation of water quantity	This ES includes water retention, storage and delayed release which are important for flood risk regulation and the rate of pollutant and nutrient transfer via runoff to surface waters (Smith et al. 2011).
2.3 Climate regulation	GHG emissions
2.4 Waste breakdown	The majority of land use types in Enclosed Farmland can provide waste breakdown services if the farmer imports waste biological material for example from for anaerobic digestion or composting. We have a limited understanding of the likely impact of AD digestate on crop response to slurry N, slurry P and the potential for fertilizer savings. The impacts depend on the digestate quality (which can vary widely), the crop nutrient uptake and the soil and environmental conditions. Whether waste breakdown on a specific field would turn out as a service or a disservice (nutrient leakage) would depend on the accuracy of the application.
2.5 Purification in soil	We are reliant upon our soils to capture and release nutrients, detoxify pollutants, and purify water. The capacity of soil for regulation is determined by the interaction of its chemical composition, physical integrity and the structure and activity of soil biodiversity (Smith et al. 2011). Here we assess whether a specific land use type or management is likely supporting this service or overburdening the capacity for regulation.
2.6 Disease and pest regulation	The service of providing habitat, shelter and food resources for natural biocontrol agents (in soil and aboveground) and suppress soil-dwelling pests and pathogens is balanced against the disservice of promoting or introducing pest species or pathogens.
2.7 Pollination	Pollination is provided by managed honey bees (*Apis mellifera*) and a wide range of wild insect species including bumblebees, solitary bees, hoverflies, butterflies and moths (Firbank et al. 2011). Here we assess whether land use and management would enhance pollination by providing high quality habitat for pollinating insects such as flower-rich landscape elements and nesting sites. Pesticide applications also have to be taken into account (Brittain et al. 2010).
3. Cultural services	
3.1 Environmental settings – socially valued landscapes	Here we assess to which degree agricultural landscapes provide meaningful places for individuals. This varies according to the nature of the landscape itself, its accessibility and the variation in values and attitudes of people (Firbank et al. 2011). In the UK, rural landscapes have a have a strong "sense of place" and the English value the lowland agricultural landscapes because they symbolise continuity, social stability and a productive nature (Firbank et al. 2011).
3.2 Wild species diversity and wildlife habitat	Biodiversity here is assessed as a cultural service because the characteristics of environmental settings that constitute those services can be affected by the absence or presence of wild species (Church et al. 2011). Human interactions with animals and plants can generate cultural goods partly because people value environmental settings where certain types of animals or plants are present (e.g. existence of emblematic species, bird songs, flowering meadows etc.; Church et al. 2011). In agricultural landscapes, biodiversity is greatest where there is heterogeneity of habitats over multiple scales of space and time (Benton *et al.* 2003).

Agroecosystems are not only providers of ES but management practices also influence the potential of disservices or disbenefits from agriculture (Zhang et al. 2007; Power 2010). In the traffic light assessment, a green light is given when the respective service is provided and a red light when a disservice occurs (Table 2). The yellow light either stands for a division of service and disservice provision by the respective types of land use within the farm or inconclusive outcomes of the ES, often depending on specific management decisions by the farmer. Plus and minus characters depict the expected direction and value of an impact (Table 2). Furthermore, an "o" is entered in the table if opportunities exist for improving the outcome of an ES and an exclamation mark "!" shall raise awareness if caution in respect to the sensitivity of an ES provision is advised (Table 2). The ES assessments are specific for the respective farm type, the proportions of land use types within the farm and changes in crop rotations when applicable. The wider landscape settings (i.e.: landscape composition, topography, soils) are also taken into consideration. Effects of AD development on indirect land-use change were not taken into account for the ES assessments.

Table 2: **Color coding and characters used in the ES assessment to illustrate the direction and value range of impacts from farming and AD practices**

ES traffic light assessment scheme		Impact value range		
	Direction of impact	High	Medium	Low
Service provided	+	+++	++	+
Disservice provided	-	---	--	-
Inconclusive/divided	+/-			
Not applicable				
Opportunity exists	o	ooo	oo	o
Caution advised	!	!!!	!!	!

3. Results large dairy farm

Large dairy farm baseline (LD-BL)

The large dairy farm largely depends on imported feed for the milk cows because the number of cows on the farm exceeds the scale of on-farm feed production and therefore has an impact on land-use elsewhere. The fodder produced on-farm is here not assessed as a disservice to food production because it is a necessary part of the dairy and beef production process. We concede that a different viewpoint can be taken. If we assume that the production of concentrate feed uses prime agricultural land which could alternatively be used for food production, this competition would fundamentally change the outcome of our ES assessment from green to yellow or even red, depending on the type and origin of feed. If we assume that the feed is imported from overseas and given an upper-end yield level of 2.74 t per ha of soy (yield level for Argentina given by Masuda & Goldsmith 2009), the imported feed would require a minimum land area of 355 ha. Hence, large areas of land outside the farm are utilized in addition to the on-farm land use. This off-farm land use even increases with increasing need for feed import for the AD grass and maize scenarios. The ES impact of the off-farm land use depends on the type of feed and the area on the globe in which it is produced. Taking all possible options into account is beyond the scope of the present ES assessment. Nevertheless, one has to keep in mind that potential competition between food and feed production on the land utilized outside the farm could turn the provisioning service of food production (Table 3) into a disservice.

Table 3: Ecosystem service (ES) assessment for the large dairy farm baseline (LD-BL)

Final and intermediate ES	ES status				
	Grazing grass	Silage grass	Fodder maize	Livestock	Farm total
	13 ha	41.8 ha	195.2 ha		250 ha
1. Provisioning services					
1.1 Food				+++ !!	
1.2 Fodder	+	++	+++		
1.3 Biomass for energy		o	o	o	
1.4 Water supply	+/-	+/-	+	---	
1.5 Wild species diversity	--	--	--	-	
1.6 Carbon sequestration	+/-	+/-	--		
2. Regulating services					
2.1 Hazard regulation	+ !	+ o	--- !	!	
2.2 Regulation of water quantity	+ !	+ !	-- !		
2.3 Climate regulation	-	-	--	---	
2.4 Waste breakdown	+	+	+	---	
2.5 Purification in soil	+/-	+/-	---		
2.6 Disease and pest regulation	-	-	--		
2.7 Pollination	-	-	-		
3. Cultural services					
3.1 Environmental settings – socially valued landscapes	+/-	+/-	-	-	
3.2 Wild species diversity and wildlife habitat	--	--	---		

LD-BL 1.1 The farm produces milk as the primary food source and some beef in addition.

LD-BL 1.2 The major purpose of the farm land use is production of feed for the cows. Most grassland is managed in the form of 'improved' pasture or long-term leys using herbicides, fertilisers, ploughing, reseeding, liming and drainage to favour competitive, nitrogen-responsive grasses which provide silage (Firbank et al. 2011).

LD-BL 1.3 Surplus silage grass or fodder maize could be sold to external AD plants. This would however increase the amount of feed which would have to be imported. Food waste from dairy production or carcasses could be used in external AD plants.

LD-BL 1.4 Levels of water abstraction by maize are low to medium and the crop has a high water efficiency for Atlantic Central (SRU 2007, 42; EEA 2007, 105 and 116). Maize, however, has a tendency for soil compaction leading to increased surface run-off (See LD-BL 2.1). Water abstraction by silage grass is higher than by maize but percolation might be higher as well. The groundwater recharge on the farmland is counteracted by high water abstraction for the livestock and dairy production. For the 481 milk cows alone 52910 liters of water per day are necessary for drinking and washing (compare NIEA: http://www.doeni.gov.uk/niea/agriculture_ready_reckoner.pdf).

LD-BL 1.5 The enclosed farmland in which the baseline farm is located is unlikely to provide many resources for bioprospecting or genetic material for plant breeding. No rare breeds of cattle are used in such intensive dairy production systems. Some medicinal plants, wild food, game and deer might be provided but their provision largely depends on the existence and management of field margins and hedgerows (Berry et al. 2011, 711).

LD-BL 1.6 Maize shows strong negative humus reproduction rates in arable soils (Brock et al. 2013). Improved grassland management, including multiple harvests and reseeding, can deplete soil carbon stocks. Direct sowing is the most common method of establishment and for this the existing sward is ploughed in and allowed to rot for a few weeks, harrowed, fertilized and rolled before sowing (Smyth et al. 2009). Direct drilling, which is a method of seeding without ploughing, might be an option for reducing carbon loss from the soil. Organic fertilizer might help to improve soil carbon content.

LD-BL 2.1 Soil erosion by water is high in maize. Particular caution is advised for fields located on slopes. In grasslands erosion hazard exists after ploughing and reseeding. The permanent vegetation cover of the grassland reduces the risk of wind or water erosion. An additional reduction of erosion hazard could be provided by direct drilling for reseeding because no ploughing of the soil is required and there is no vegetation-free phase involved in the crop management. Grazed grassland can be prone to erosion if the livestock units per ha are too high, leading to compacted soil and damaged turf structure.

LD-BL 2.2 There is a long vegetation-free phase in maize during which it is susceptible to strong surface runoff (Grunewald & Bastian 2013, 124). Maize stubble left over winter can be prone to overland run-off leading to water pollution (soil sediments and associated phosphorous) and flooding (Defra 2011). Water-holding capacity can be increase by increasing soil organic matter content and improving soil structure (Bardgett et al. 2011, 507). Managing for a greater complexity and diversity of the soil food web would help to increase storage and retention of nutrients and transformation of pollutants that might otherwise enter the water (Bardgett et al. 2011, 507).

LD-BL 2.3 There is a strong negative score for Enclosed Famland, due to emissions of GHG and depletion of carbon in soils (Firbank et al. 2011, 212). The LD-BL system is responsible for GHG emissions of over 14 t CO_2e per ha per yr according to the LCAD tool.

LD-BL 2.4 Slurry can be applied as organic fertilizer to silage grass and maize. In the baseline scenario, there is a sufficient land bank on the farm for the slurry produced.

LD-BL 2.5 Improved grasslands are fertilized with organic and inorganic fertilizers. There are few weeds that can invade the fields which cannot be eaten by grazing stock, e.g. greater plantain, creeping thistle and ragwort, so herbicides are often used to control them (Environment & Heritage Service 2005). The risk of nutrient and pesticide inputs to ground and surface water by improved grasslands depends on the amount applied and the correct timing of the applications. The risk of nutrient inputs to ground and surface water by maize is medium to high (EEA 2007, 105). Nitrogen application rates are high for the grass areas of the LD-BL farm.

LD-BL 2.6 Re-seeding and fertilization decrease plant diversity in grasslands and thus reduce food source availability for invertebrates, furthermore grazing and cutting reduce tussock grass structures which provide shelter for invertebrates (Potts et al. 2009). Maize hosts a low number of weed species (Waldhardt et al. 2011) and thus provides little alternative resources such as shelter or food for biocontrol agents.

LD-BL 2.7 Number of flowering plant species is very low on conventional improved grasslands and number of insect pollinators is also low, reflecting the poor provision of food resources (Power & Stout 2011). Due to low numbers of weeds in maize crops, no additional food resource for pollinating insects is provided. Maize pollen foraging by honey bees was found to be low, representing a minor proportion of the total pollen spectrum and thus the contribution of maize pollen to the protein diet of honeybees appears to be of minor importance (Härtel et al. 2010).

LD-BL 3.1 The southwest England landscape context of the farm is dominated by permanent and temporary grassland. Hence the silage grassland of the baseline farm fits well into the general context. However, those grasslands may contain just one or two plant species and are of little wildlife or scenic value. According to Natural England (2009a) grassland not containing wild untouched meadows with wild flowers is not regarded as a very interesting type of landscape. The maize fields might stick out as alien to the landscape setting. Grazing heifers might benefit the scenic beauty of the landscape but they are only out on the pasture for two months. The large stable necessary to house the large herd might not be regarded as a scenic addition to the landscape.

LD-BL 3.2 Plant species richness in improved grassland decreased by 11.9% in Great Britain between 1998 and 2007 and by 21.8% between 1990 and 2007 (Countryside Survey 2007). There has been a trend towards further intensification, by using non-native strains of grasses, which out-compete native strains, combined with heavy use of fertilisers. The trend towards cutting grass earlier in the season has also affected ground-nesting birds that breed in improved grassland (http://www.kent.gov.uk/klis/resources/factsheets/habitat_fr/Improved_Grasslands.pdf). Ploughing and reseeding old pastures with rye-grass (Lolium) swards eliminates larval food plants of British butterflies (Boatman et al. 2007). Maize cultivated as monoculture poses medium to high risk for conservation of farmland biodiversity although it might provide some shelter for fauna in autumn due to late harvest (EEA 2007, 105).

It is assumed that there will be virtually no change in the direct ecosystem service provisioning of the LD-BL farm upon introduction of an AD unit fed by slurry alone (LD-S), as no land use changed will be incurred. However, significant reductions in global warming potential (-19%), eutrophication potential (-29%) and acidification (-52%) translate into reductions in the scale of negative effects on climate and water quality regulation.

Large dairy farm AD scenarios (LD-SG and LD-SMZ)

The two AD scenarios LD-SG and LD-SMZ are very similar with respect to on-farm land-use change. The major difference between the scenarios is that different feedstock, either grass or maize silage, enters the AD plant. This difference has little impact on the outcome of the ES assessment. Therefore both scenarios were assessed together.

Table 4: Ecosystem service (ES) assessment for the large dairy farm AD scenarios (LD-SG and LD-SMZ).

Final and intermediate ES	ES status				
	Grazing grass	**Silage grass**	**Fodder maize**	**Livestock**	**Farm total**
	1 ha	63.4 ha	185.6 ha		250 ha
1. Provisioning services					
1.1 Food				+++ !!	
1.2 Fodder	+/-	++	++		
1.3 Biomass for energy		++	++	++	
1.4 Water supply	+/-	+/-	+	---	
1.5 Wild species diversity	-	--	--	-	
1.6 Carbon sequestration	+/-	+/-	--		
2. Regulating services					
2.1 Hazard regulation	+/- !	+	--- o		
2.2 Regulation of water quantity	+/-	+ !	-- !		
2.3 Climate regulation	-	+/-	-	--	
2.4 Waste breakdown	+/-	+	+	--	
2.5 Purification in soil	+/-	+/-	---		
2.6 Disease and pest regulation	-	-	--		
2.7 Pollination	-	-	- o		
3. Cultural services					
3.1 Environmental settings – socially valued landscapes	+/-	+/-	-	-	
3.2 Wild species diversity and wildlife habitat	--	--	---		

LD-SG/SMZ 1.1 The farm still produces milk as the primary food source and some beef in addition. The amount of imported feed increases by about 40% in comparison with the baseline and thus the ES impacts of indirect land-use change increase.

LD-SG/SMZ 1.2 The shift from improved grassland additionally used for grazing to pure silage grassland has no impact on fodder production. Either grass silage (from 38.4 ha) or maize silage (from 26 ha) is now fed to the AD plant and the cows are fed by greater quantities of imported feed. Still large quantities of fodder are produced on-farm. The major ES impacts associated with this change happen due to indirect land-use change, most likely outside the UK.

LD-SG/SMZ 1.3 Grass or maize silage as well as slurry produced on the farm are now fed into the AD plant.

LD-SG/SMZ 1.4 The number of milk cows and heifers remains constant. There is some additional water abstraction required for running the AD plant.

LD-SG/SMZ 1.5 No changes compared to baseline.

LD-SG/SMZ 1.6 No changes compared to baseline. Use of digestate for fertilization might improve soil carbon content in the long run.

LD-SG/SMZ 2.1 Due to the large land area with maize in monoculture the risk of erosion remains high. The possible concentration of grazing animals onto a smaller area could increase trampling and erosion risk. Undersowing with grasses or clover in maize could provide the opportunity of reduced risk of erosion.

LD-SG/SMZ 2.2 No changes compared to baseline.

LD-SG/SMZ 2.3 Significant lifecycle reductions in global warming potential (-10%), eutrophication potential (-15%) and acidification (-46%) in LCAD default scenarios for maize (smaller reductions for grass) AD lead to reductions in the scale of negative effects on climate and water quality regulation. Nonetheless, overall farm burdens remain high and relatively unchanged for the baseline. If additional feed is provided with SBME associated with loss of forest and grassland in source countries, then lifecycle GHG emissions increase, leading to a climate regulation disservice.

LD-SG/SMZ 2.4 Transformation of slurry to AD digestate might improve the waste breakdown potential for the farmland and reduce risks of nutrient leaching due to better plant availability of nutrients from digestate (FNR 2012a).

LD-SG/SMZ 2.5 No change in comparison to baseline. A long term potential for improved soil structure through application of digestate exists.

LD-SG/SMZ 2.6 No changes compared to baseline.

LD-SG/SMZ 2.7 No changes compared to baseline. Alternative energy crops such as *Silphium perfoliatum* or wild plant mixtures could provide pollen and nectar resources for pollinators and would increase habitat diversity.

LD-SG/SMZ 3.1 No changes compared to baseline. The AD plant might be an additional impact to the scenic quality of the landscape.

LD-SG/SMZ 3.2 No changes compared to baseline.

Large dairy farm Miscanthus scenario (LD-M)

The production of Miscanthus for bioenergy leads to reduced on farm feed production. Therefore additional 237 tonnes of feed have to be imported.

Table 5: Ecosystem service (ES) assessment for the large dairy farm Miscanthus scenario (LD-M)

Final and intermediate ES	ES status					
	Grazing grass	Silage grass	Fodder maize	Livestock	Miscanthus	Farm total
	1 ha	57.6 ha	166.5 ha		25	250 ha
1. Provisioning services						
1.1 Food				+++ !!		
1.2 Fodder	+/-	++	++			
1.3 Biomass for energy		o	o	o	++	
1.4 Water supply	+/-	+/-	+	---	-	
1.5 Wild species diversity	--	--	--	-	-	
1.6 Carbon sequestration	+/-	+/-	--		+	
2. Regulating services						
2.1 Hazard regulation	+/-	+	--- o		+	
2.2 Regulation of water quantity	+/-!	+	--		+ o	
2.3 Climate regulation	-	-	--	---	+	
2.4 Waste breakdown	+	+	+	---	-	
2.5 Purification in soil	+/-	+/-	---		+	
2.6 Disease and pest regulation	-	-	--		+/-	
2.7 Pollination	-	-	-		+/-	
3. Cultural services						
3.1 Environmental settings – socially valued landscapes	+	+/-	-	-	+/-	
3.2 Wild species diversity and wildlife habitat	-	-	-		+/-	

LD-M 1.1 No changes in comparison to baseline scenario. More feed needs to be imported for to compensate lower feed production on farm.

LD-M 1.2 Only minor reductions of grass silage and maize silage production.

LD-M 1.3 High yield for Miscanthus is predicted for most parts of Devon (http://archive.defra.gov.uk/foodfarm/growing/crops/industrial/energy/opportunities/pdf/yield/miscanthus/sw_miscanthus_yield_250.pdf)

LD-M 1.4 Due to the high water requirements of Miscanthus and the loss of percolation, detectable reductions in aquifer recharge might occur at the sub-catchment scale, if the land cover of miscanthus is too high to be compensated by conventional crops (Stephens et al. 2001).

LD-M 1.5 No changes in comparison to baseline.

LD-M 1.6 There is a general consensus that the conversion of arable land to Miscanthus will result in an increase in carbon sequestration (Rowe et al. 2009). In particular planting on former maize fields will help improving the situation. The area of Miscanthus compared to maize is too low to turn the disservice of carbon loss due to maize cultivation into a service at the farmscale.

LD-M 2.1 Miscanthus grown on former maize fields will significantly reduce the risk of soil erosion. Similar to LD-M 1.6, the area of Miscanthus cultivation in comparison to maize cultivation is too low to change the disservice into a service at the farmscale. Undersowing of maize with grasses or clover provide the opportunity of reduced risk of erosion.

LD-M 2.2 The high water use of Miscanthus could be utilized in flood management to reduce flooding in risk areas (Rowe et al. 2009). Miscanthus located downhill from maize fields could reduce the run-off from those fields into streams.

LD-M 2.3 Miscanthus cultivation and use leads to a significant lifecycle reduction in global warming potential (-7%), but increases in eutrophication and acidification potentials according to LCAD default scenarios for miscanthus (iLUC selected). If additional feed is provided with SBME associated with loss of forest and grassland in source countries, then lifecycle GHG emissions increase, leading to a climate regulation disservice.

LD-M 2.4 Waste application on Miscanthus might not be advisable due to its low fertilizer requirements. In an Irish study, spread of distillery effluent resulted in excessive PO_4^{3-} in the plot groundwater which was likely due to high background soil P, soil characteristics, and the occurrence of soil macropore flow (Galbally et al. 2012).

LD-M 2.5 There is a low risk of nutrient or pesticide leaching to ground and surface water by Miscanthus for Atlantic Central (EEA 2007, 114).

LD-M 2.6 There is some potential for the western corn rootworm *Diabrotica virgifera virgifera* LeConte (Coleoptera: Chrysomelidae), a destructive maize pest, as well as for stem-boring caterpillars such as *Diatraea grandiosella* Dyar (Lepidoptera: Crambidae) to become significant pests of Miscanthus (Gloyna et al. 2011; Prasifka et al. 2012). This could negatively affect the maize production on the farm. At the same time, Miscanthus might serve as an overwintering habitat for epigeic arthropods and act as a source habitat for the colonization of adjacent maize fields.

LD-M 2.7 In landscapes dominated by arable farming, land-use change from conventional crops to Miscanthus on a small scale may result in increases in some pollinator groups, especially solitary bees (Stanley & Stout 2013). Miscanthus may support a diverse and abundant within-field plant community that can be beneficial for flower visiting insects; in addition, Miscanthus might provide nesting opportunities due to its low-disturbance, perennial nature and potential nest sites offered by dead stems left in the field after harvesting (Stanley & Stout 2013). If, however, Miscanthus fields were weed-free at all times, e.g. due to a very dense crop cover, their positive effects on pollinating insects would be diminished.

LD-M 3.1 An assessment of the sensitivity of the Devon landscape to Miscanthus production revealed moderate to high sensitivity levels for almost the entire county (Thumim & White 2007). For the more agriculture dominated areas some opportunity to accommodate Miscanthus is seen but care is needed in locating crops so they do not dominate the landscape, or detract from key characteristics of the landscape (Thumim & White 2007). This study concludes that there is significant potential for cultivation of Miscanthus in Devon without compromising the existing landscape character, but the precise quantity that could be accommodated would require further consideration. For the present farm, accommodation of both maize and Miscanthus without compromising the landscape character might be difficult.

LD-M 3.2 The perennial nature and the low pesticide and nitrogen applications to Miscanthus suggest positive impacts on biodiversity within agricultural settings (EEA 2007, 110, 116). A couple of studies from the UK and Ireland report positive effects on birds, invertebrates and plants but our understanding of the potential effects of Miscanthus on biodiversity is limited to studies of plantations during the establishment phase, which is characterized by patchy crop cover (Rowe et al. 2009, Bourke et al. in press). Mature high yielding monoculture plantings of Miscanthus may offer very little by way of habitat to local flora and fauna (Berry et al. 2011). Therefore, if Miscanthus fields had a closed canopy and were kept weed-free at all times, their invertebrate populations were bound to resemble that of arable crops (McKervey et al. 2008). There have been some concerns whether Miscanthus, as an introduced species, might be an invasive plant but this is not a problem as long as sterile hybrid varieties are used (McKervey et al. 2008).

4. Results average (medium) dairy farm

Medium dairy farm baseline (MD-BL)

Just like for the large dairy farm, but to a lesser extent, the medium dairy farm depends on imported feed for the milk cows because the number of cows on the farm exceeds the scale of on-farm feed production. Those feed imports have an impact on land use and hence ES provisioning elsewhere. Drawing on the same example of soy-based feed imported from Argentina mentioned for the large dairy farm, the medium dairy farm would utilize an area of about 61 ha outside the farm to import 167 tonnes of feed.

Table 6: Ecosystem service (ES) assessment for the medium dairy farm baseline (MD-BL)

Final and intermediate ES	ES status				
	Grazing grass	Silage grass	Fodder maize	Livestock	Farm total
	45.6 ha	7.1 ha	32.3 ha		85 ha
1. Provisioning services					
1.1 Food				+++ !!	
1.2 Fodder	++	+	++		
1.3 Biomass for energy			o	o	
1.4 Water supply	+/-	+/-	+	--	
1.5 Wild species diversity	--	-	--	-	
1.6 Carbon sequestration	+/-	+/-	--		
2. Regulating services					
2.1 Hazard regulation	+ !	+	--- !	!	
2.2 Regulation of water quantity	+ !	+ !	-- !		
2.3 Climate regulation	-	-	--	---	
2.4 Waste breakdown	+/- !	+	+	---	
2.5 Purification in soil	+/-	+/-	---		
2.6 Disease and pest regulation	-	-	--		
2.7 Pollination	-	-	-		
3. Cultural services					
3.1 Environmental settings – socially valued landscapes	+	+/-	-	+/-	
3.2 Wild species diversity and wildlife habitat	--	--	---		

MD-BL 1.1 The farm produces milk as the primary food source and some beef in addition.

MD-BL 1.2 The major purpose of the farmland is production of feed for the cows. Most grassland is managed in the form of 'improved' pasture or long-term leys using herbicides, fertilisers, ploughing, reseeding, liming and drainage to favour competitive, nitrogen-responsive grasses which provide silage (Firbank et al. 2011)

MD-BL 1.3 Surplus fodder maize could be sold to external AD plants. This would however increase the amount of feed which would have to be imported. Food waste of dairy production or carcasses could be used in external AD plants.

MD-BL 1.4 Levels of water abstraction by maize are low to medium and the crop has a high water efficiency for Atlantic Central (SRU 2007, 42; EEA 2007, 105 and 116). Maize, however, has a tendency for soil compaction leading to increased surface run-off (See MD-BL 2.1). Water abstraction by silage grass is higher than by maize but percolation might be higher as well. The groundwater recharge on the farmland is counteracted by high water abstraction for the livestock and dairy production. For the 125 milk cows alone 12500 liters of water per day are necessary for drinking and washing (compare NIEA: http://www.doeni.gov.uk/niea/agriculture_ready_reckoner.pdf).

MD-BL 1.5 The enclosed farmland the baseline farm is located in is unlikely to provide many resources for bioprospecting or genetic material for plant breeding. No rare breeds of cattle are used in such intensive dairy production systems. Some medicinal plants, wild food, game and deer might be provided but their provision largely depends on the existence and management of field margins and hedgerows (Berry et al. 2011, 711).

MD-BL 1.6 Maize results in strong negative humus reproduction rates in arable soil (Brock et al. 2013). Improved grassland management including multiple harvests and reseeding can deplete soil carbon stocks. Direct sowing is the most common method of establishment and for this the existing sward is ploughed in and allowed to rot for a few weeks, harrowed, fertilized and rolled before sowing (Smyth et al. 2009). Direct drilling, which is a method of seeding without ploughing, might be an option for reducing carbon loss from the soil. Organic fertilizer might help to improve soil carbon content.

MD-BL 2.1 Soil erosion by water is high in maize. Particular caution is advised for fields located on slopes. In grasslands erosion hazard exists after ploughing and reseeding. The permanent vegetation cover of the grassland reduces the risk of wind or water erosion. An additional reduction of erosion hazard could be provided by direct drilling for reseeding because no ploughing of the soil is required and there is no vegetation-free phase involved in the crop management. Grazed grassland can be prone to erosion if the livestock units per ha are too high, leading to compacted soil and damaged turf structure.

MD-BL 2.2 There is a long vegetation-free phase in maize during which it is susceptible to strong surface runoff (Grunewald & Bastian 2013, 124). Maize stubble left over winter can be prone to overland run-off leading to water pollution (soil sediments and associated phosphorous) and flooding (Defra 2011). Water-holding capacity can be increase by increasing soil organic matter content and improving soil structure (Bardgett et al. 2011, 507). Trampling by cattle might damage soil structure if livestock units per ha are too high.

MD-BL 2.3 Strong negative score of Enclosed Famland, due to emissions of GHG and depletion of carbon in soils (Firbank et al. 2011, 212). The baseline farm results in net GHG emissions of 13 t CO_2e per ha per yr according to the LCAD tool.

MD-BL 2.4 Slurry can be applied as organic fertilizer to silage grass and maize. There is a sufficient land bank on this farm to receive the slurry produced by the housed cattle without generating nutrient surpluses. Slurry application on grazed grassland requires more caution and an appropriate application technique. Spreading with splash plates can contaminate the sward and affect grazing behavior of cattle (Dale & Ferris 2011). Nutrient recycling in grazing systems takes place via faeces and urine deposited by the grazing animal and therefore caution is required when utilizing additional slurry to ensure that there will be no detrimental effect on the nutrient balance of the grassland (Dale & Ferris 2011).

MD-BL 2.5 The risk of nutrient and pesticide inputs to ground and surface water by improved grasslands depends on the amount applied and the correct timing of the applications. The risk of nutrient inputs to ground and surface water by maize is medium to high (EEA 2007, 105).

MD-BL 2.6 Re-seeding and fertilization decrease plant diversity in grasslands and thus reduce food source availability for invertebrates, furthermore grazing and cutting reduce tussock grass structures which provide shelter for invertebrates (Potts et al. 2009). Maize hosts a low number of weed species (Waldhardt et al. 2011) and thus provides little alternative resources such as shelter or food for biocontrol agents.

MD-BL 2.7 Number of flowering plant species is very low on conventional improved grasslands and number of insect pollinators is also low, reflecting the poor provision of food resources (Power & Stout 2011). Due to low numbers of weeds in maize crops, no additional food resource for pollinating insects is provided. Maize pollen foraging by honey bees was found to be low, representing a minor proportion of the total pollen spectrum and thus the contribution of maize pollen to the protein diet of honeybees appears to be of minor importance (Härtel et al. 2010).

MD-BL 3.1 The southwest England landscape context of the farm is dominated by permanent and temporary grassland. Hence the silage grassland of the baseline farm fits well into the general context. However, those grasslands may contain just one or two plant species and are of little wildlife or scenic value. According to Natural England (2009a) grassland not containing wild untouched meadows with wild flowers is on the whole not regarded as a highly interesting type of landscape. The maize fields might stick out as alien to the landscape setting. Grazing cattle might benefit the scenic beauty of the landscape in particular because they are out on the pasture for six month.

MD-BL 3.2 Ploughing and reseeding old pastures with rye-grass (Lolium) swards eliminates larval food plants of British butterflies (Boatman et al. 2007). Maize cultivated as monoculture poses medium to high risk for conservation of farmland biodiversity although it might provide some shelter for fauna in autumn due to late harvest (EEA 2007, 105).

Medium dairy beef plus AD scenario (BAD-SGMZ)

The BAD-SGMZ scenario involves a fundamental change to the farm system. The dairy farm is transformed into an energy farm with additional beef production. The landscape composition does not change much in comparison to the baseline farm but due to a reduced intensity of the livestock system less feed import is required. Beef cattle are grazed on the silage grass after AD feedstock harvest.

Table 7: Ecosystem service (ES) assessment for the beef and AD scenario (BAD-SGMZ)

Final and intermediate ES	ES status				
	Grazing grass	Silage grass	Fodder maize	Livestock	Farm total
	0 ha	53 ha	32 ha		250 ha
1. Provisioning services					
1.1 Food				+	
1.2 Fodder		+	+		
1.3 Biomass for energy		++	++	o	
1.4 Water supply		+/-	+	-	
1.5 Wild species diversity		--	--	-	
1.6 Carbon sequestration		+/-	--		
2. Regulating services					
2.1 Hazard regulation		++ o	--- !		
2.2 Regulation of water quantity		+ !	-- !		
2.3 Climate regulation		--	--	---	
2.4 Waste breakdown		+ !	+	--	
2.5 Purification in soil		+	--		
2.6 Disease and pest regulation		-	--		
2.7 Pollination		-	- o		
3. Cultural services					
3.1 Environmental settings – socially valued landscapes		+/- o	-	-	
3.2 Wild species diversity and wildlife habitat		- o	-		

BAD-SGMZ 1.1 The farm changes food production from dairy to beef. However, owing to most of the grass and maize being used for the AD unit, and less feed being imported, overall beef production is lower than animal live weight export from the MD-BL scenario (though beef is of a higher quality than milk cow carcasses and therefore not directly comparable). Nonetheless, combined with a loss of milk production of 1,013,548 L per year compared with the MD-BL scenario, this scenario represents such an inefficient use of land for food production that it could be perceived as resulting in a disservice for food production (shaded orange).

BAD-SGMZ 1.2 Silage grass and maize is produced as fodder for the beef cows, but most goes to the AD unit.

BAD-SGMZ 1.3 A higher share of the silage grass and maize are going as feedstock into the AD plant.

BAD-SGMZ 1.4 In comparison to the dairy farm, water abstraction by the beef cattle is much reduced to 800 L per day for drinking.

BAD-SGMZ 1.5 No fundamental change in comparison to baseline farm.

BAD-SGMZ 1.6 No fundamental change in comparison to baseline farm.

BAD-SGMZ 2.1 The lower risks for soil erosion of the silage grassland cannot compensate the high risk associated with maize cultivation. Erosion induced by cattle trampling can be reduced through appropriate livestock units per ha. Undersowing of maize with grasses or clover provide the opportunity of reduced risk of erosion.

BAD-SGMZ 2.2 No fundamental change in comparison to baseline farm.

BAD-SGMZ 2.3 This scenario results in disservices to climate regulation, eutrophication and acidification according to the LCAD tool when iLUC is considered in default scenario settings.

BAD-SGMZ 2.4 Cattle can reject grass contaminated with untreated slurry but they do not readily reject grass spread with digestate. Pathogens such as salmonella are lowered in digestate compared to slurry (http://www.afbini.gov.uk/index/services/specialist-advice/renewable-energy/re-anaerobic-digestion-intro/re-anaerobic-digestion-benefits.htm). Still caution is required when utilizing digestate as additional fertilizer to faeces and urine to ensure that there will be no detrimental effect on the nutrient balance.

BAD-SGMZ 2.5 Fertilization with digestate could in the long term improve soil structure and soil foodwebs. Nutrients from digestate are less prone to leaching. Inputs of herbicides could potentially be reduced.

BAD-SGMZ 2.6 No fundamental change in comparison to baseline farm.

BAD-SGMZ 2.7 No fundamental change in comparison to baseline farm. Alternative energy crops such as *Silphium perfoliatum* or wild plant mixtures could provide pollen and nectar resources for pollinators and would increase habitat diversity.

BAD-SGMZ 3.1 Stables for the beef cows could be smaller and better integrated into the landscape but this effect on the landscape setting might be counteracted by the AD plant. There might be an option to manage for more flower rich grasslands to increase the scenic value.

BAD-SGMZ 3.2 No fundamental change in comparison to baseline farm. There might be an option to manage for more flower rich grasslands to increase the biodiversity.

Medium dairy farm Miscanthus scenario (MD-M)

In contrast to the large dairy farm, Miscanthus on the small farm will be established on grassland. The area for maize will remain the same. The amount of imported feed will rise because number of dairy cows remains almost constant in comparison to the baseline farm. The impacts on ES outside the farm therefore increase due to the indirect land-use change induced, as shown for the additional feed footprint in the LCAD tool.

Table 8: Ecosystem service (ES) assessment for the small dairy farm Miscanthus scenario (MD-M)

Final and intermediate ES	ES status					
	Grazing grass	Silage grass	Fodder maize	Livestock	Miscanthus	Farm total
	28 ha	6.2 ha	32.3 ha		8.5	85 ha
1. Provisioning services						
1.1 Food				+++		
1.2 Fodder	+	+	++			
1.3 Biomass for energy	o	o	o	o	+	
1.4 Water supply	+/-	+/-	+	---	-	
1.5 Wild species diversity	--	--	--	-	-	
1.6 Carbon sequestration	+/-	+/-	--		+/-	
2. Regulating services						
2.1 Hazard regulation	+	+	---		+	
2.2 Regulation of water quantity	+	+	--		+	
2.3 Climate regulation	-	-	--	---	+	
2.4 Waste breakdown	+	+	+	---	-	
2.5 Purification in soil	+/-	+/-	---		+	
2.6 Disease and pest regulation	-	-	--		+/-	
2.7 Pollination	-	-	-		+/-	
3. Cultural services						
3.1 Environmental settings – socially valued landscapes	+	+/-	-	-	+/-	
3.2 Wild species diversity and wildlife habitat	-	-	-		+/-	

MD-M 1.1 No fundamental change in comparison to baseline farm.

MD-M 1.2 Less feed produced on-farm resulting in higher feed imports.

MD-M 1.3 High yield for Miscanthus is predicted for most parts of Devon (http://archive.defra.gov.uk/foodfarm/growing/crops/industrial/energy/opportunities/pdf/yield/miscanthus/sw_miscanthus_yield_250.pdf).

MD-M 1.4 Due to the high water requirements of Miscanthus and the loss of percolation, detectable reductions in aquifer recharge might occur at the sub-catchment scale, if the land cover of miscanthus is too high to be compensated by conventional crops (Stephens et al. 2001).

MD-M 1.5 No fundamental change in comparison to baseline.

MD-M 1.6 Establishment of Miscanthus on grassland might not necessarily lead to a carbon dept but can result in a relocation of soil organic carbon to lower levels of the soil profile without carbon emissions occurring (Zimmermann et al. 2012). Nevertheless it remains to be seen whether Miscanthus cultivation is resulting in higher soil carbon levels compared to improved grassland. The outcome of this comparison will largely depend on the frequency of ploughing and reseeding of the grassland.

MD-M 2.1 Miscanthus will reduce the risk of soil erosion. Undersowing with grasses or clover provide the opportunity of reduced risk of erosion. Undersowing of maize with grasses or clover provide the opportunity of reduced risk of erosion.

MD-M 2.2 The high water use of Miscanthus could be utilized in flood management to reduce flooding in risk areas (Rowe et al. 2009). Miscanthus located downhill from maize fields could reduce the run-off from those fields into streams.

MD-M 2.3 Miscanthus cultivation and use leads to a significant lifecycle reduction in global warming potential (-7%), but increases in eutrophication and acidification potentials according to LCAD default scenarios for miscanthus (iLUC selected). If additional feed is provided with SBME associated with loss of forest and grassland in source countries, then lifecycle GHG emissions increase, leading to a climate regulation disservice.

MD-M 2.4 Less land is available for slurry application while the amount of slurry produced by the livestock remains constant.

MD-M 2.5 There is a low risk of nutrient or pesticide leaching to ground and surface water by Miscanthus for Atlantic Central (EEA 2007, 114).

MD-M 2.6 There is some potential for the western corn rootworm *Diabrotica virgifera virgifera* LeConte (Coleoptera: Chrysomelidae), a destructive maize pest, as well as for stem-boring caterpillars such as *Diatraea grandiosella* Dyar (Lepidoptera: Crambidae) to become significant pests of Miscanthus (Gloyna et al. 2011; Prasifka et al. 2012). This could negatively affect the maize production on the farm. At the same time, Miscanthus might serve as an overwintering habitat for epigeic arthropods and act as a source habitat for the colonization of adjacent maize fields.

MD-M 2.7 In landscapes dominated by arable farming, land-use change from conventional crops to Miscanthus on a small scale may result in increases in some pollinator groups, especially solitary bees (Stanley & Stout 2013). Miscanthus may support a diverse and abundant within-field plant community that can be beneficial for flower visiting insects; in addition, Miscanthus might provide nesting opportunities due to its low-disturbance, perennial nature and potential nest sites offered by dead stems left in the field after harvesting (Stanley & Stout 2013). If, however, Miscanthus fields were weed-free at all times, e.g. due to a very dense crop cover, their positive effects on pollinating insects would be diminished.

MD-M 3.1 An assessment of the sensitivity of the Devon landscape to Miscanthus production revealed moderate to high sensitivity levels for almost the entire county (Thumim & White 2007). For the more agriculture dominated areas some opportunity to accommodate Miscanthus is seen but care is needed in locating crops so they do not dominate the landscape, or detract from key characteristics of the landscape (Thumim & White 2007). This study concludes that there is significant potential for cultivation of Miscanthus in Devon without compromising the existing landscape character, but the precise quantity that could be accommodated would require further consideration. For the present farm, accommodation of both maize and Miscanthus without compromising the landscape character might be difficult.

MD-M 3.2 The perennial nature and the low pesticide and nitrogen applications to Miscanthus suggest positive impacts on biodiversity within agricultural settings (EEA 2007, 110, 116). A couple of studies from the UK and Ireland report positive effects on birds, invertebrates and plants but our understanding of the potential effects of Miscanthus on biodiversity is limited to studies of plantations during the establishment phase, which is characterized by patchy crop cover (Rowe et al. 2009, Bourke et al. in press). Mature high yielding monoculture plantings of Miscanthus may offer very little by way of habitat to local flora and fauna (Berry et al. 2011). Therefore, if Miscanthus fields had a closed canopy and were kept weed-free at all times, their invertebrate populations were bound to resemble that of arable crops (McKervey et al. 2008). There have been some concerns whether Miscanthus, as an introduced species, might be an invasive plant but this is not a problem as long as sterile hybrid varieties are used (McKervey et al. 2008).

5. Results for the large arable farm

Large arable farm baseline (A-BL)

Table 9: Ecosystem service (ES) assessment for the large arable farm baseline (A-BL)

Final and intermediate ES	ES status				
	Crop rotation				Farm total
	Winter wheat 1	Winter wheat 2	Spring barley	Oil seed rape	
	100 ha	100 ha	100 ha	100 ha	400 ha
1. Provisioning services					
1.1 Food	+++	+++	+++	+++	
1.2 Fodder					NA
1.3 Biomass for energy	o	o	o	ooo	
1.4 Water supply (	+/-	+/-	+	-	
1.5 Wild species diversity	+/-	+/-	+/-	+/-	
1.6 Carbon sequestration	-	-	-	-	
2. Regulating services					
2.1 Hazard regulation	-	-	--	+/-	
2.2 Regulation of water quantity	-	-	-	-	
2.3 Climate regulation	--	--	--	--	
2.4 Waste breakdown	o	o	o	o	
2.5 Purification in soil	-	--	-	--	
2.6 Disease and pest regulation	-	-	-	--	
2.7 Pollination	--	--	-	+/-!	
3. Cultural services					
3.1 Environmental settings – socially valued landscapes	+/-	+/-	+/-	+/-	
3.2 Wild species diversity and wildlife habitat	-	-	-	-	

A-BL 1.1 Grain yields for winter wheat, spring barley and oil seed rape in the baseline scenario are slightly above the average values reported in the NFU 2012 harvest survey results.

A-BL 1.2 Fodder is not produced on the baseline arable farm.

A-BL 1.3 Within the baseline crop rotation several options for alternative bioenergy use exist. Oil seed rape could alternatively be used for biodiesel production, although different varieties might have to be cultivated. Straw from cereal production could be entered into combustion or ethanol production. Furthermore whole-plant silage of cereals is an option if low grain quality is to be expected due to e.g. adverse weather conditions during crop development.

A-BL 1.4 Most arable farmland is well drained and thus has a low water storage capacity (Berry et al. 2011, 710). In general, annual crops lead to higher recharge rates than perennial crops (Grunewald & Bastian 2013, 124). Soils of the area the baseline farm is located in are freely draining but the East of England region is one of the driest in England (Bardgett et al. 2011) and under particular pressures for water resources (Defra 2013). In general, water from arable land may have positive impacts helping to recharge aquifers but may also contribute to soil erosion and flooding and over-abstraction may damage sensitive aquatic habitats (see 2.1; Defra 2013). Water abstraction by barley is generally low but wheat has the highest water demand of all cereals (EEA 2007, 108). Water abstraction of oilseed rape is medium to high (EEA 2007, 107).

A-BL 1.5 The biodiversity of the enclosed farmland the baseline farm is located in is unlikely to provide many resources for bioprospecting or genetic material for plant breeding. Some medicinal plants, wild food, game and deer might be provided but their provision largely depends on the existence and management of cereal field margins and hedgerows (Berry et al. 2011, 711).

A-BL 1.6 The tillage regime and inputs of organic fertilizer determine the carbon store of arable soils. Increased frequency and depth of tillage, reductions in land under forage crops, predominantly mineral fertilization, and continuous use of grain cereals can lead to declines in soil organic matter, with significant losses of top soil carbon (Johnston et al. 2009).

A-BL 2.1 It has been estimated that around 2.2 million tonnes of top soil is eroded annually in England and Wales (Quinton et al. 2010). Estimates of rates of soil loss by erosion in the UK span 0.02–1.27 t/ha/yr for mineral soils, and as much as 10 t/ha/yr for tillage erosion from arable fields have been reported (Verheijen et al. 2009). In the East of England soils of all major textural classes occur on topography ranging from flat to moderately sloping. Shallow, unstable soils are prone to wind and water erosion, on sloping cultivated ground or where dry, bare soil is exposed or compacted. Areas typically affected by water erosion are gentle to moderately sloping sites (2º – 7º) under arable cultivation with sandy or silty soils or shallow soils over Cretaceous Limestone (Unwin 2001). In the crop rotation of the baseline farm, exposure of bare soil can occur after harvest and before crop cover is established. Sand blows can occur when there is insufficient protective vegetation crop cover and where windbreaks such as hedgerows, stone walls, dykes, earth banks or other common field boundary features have been removed. Processes of capping and slaking can also increase the risk of erosion. Winter wheat is often planted late in autumn with limited soil cover, therefore medium risk of erosion by wheat for Atlantic Central is assessed by the EEA (2007, 108 and 116). Spring cereals in comparison are more erodible. Early sowing with high soil coverage for oilseed rape results in a low risk of erosion for Atlantic Central (EEA 2007, 107 and 116).

A-BL 2.2 The annual crops grown on the baseline farm tend to speed up the flow of water across the farmland, thereby increasing the risk of flooding. However, the East of England is under pressure for water resources (Defra 2013).

A-BL 2.3 Generally strong negative scores are expected from enclosed farmland due to emissions and carbon depletion in soils (Firbank et al. 2011). GHG emissions of 3.1 t CO_2e per ha per yr in the LCAD tool are considerably lower than for dairy and beef rearing farm systems, but this assumes stable soil C and may therefore underestimate GHG emissions.

A-BL 2.4 Enclosed Farmland can provide waste breakdown services if the farmer imports waste biological material from anaerobic digestion or composting (Firbank et al. 2011). For the baseline farm the option exists to replace parts of the mineral fertilizers by manure or other organic waste materials.

A-BL 2.5 A medium risk of nutrient leaching to ground and surface water by wheat and barley is assessed for Atlantic Central by EEA (2007, 116). For oilseed rape in contrast a high risk of nutrient leaching to ground and surface water for Atlantic Central is assessed (EEA 2007, 116). The risk of pesticide pollution of soils and water is high in oilseed rape and wheat but lower in barley (EEA 2007, 107 and 108).

A-BL 2.6 Biological pest control is provided by a wide range of invertebrate predators and parasitoids. Habitat enhancement within crop fields (Landis et al. 2000), such as the upkeep of grass field margins, and within the wider landscape surrounding, such as upkeep of natural and seminatural vegetation (Tscharntke et al. 2005), can have positive effects on the abundance of natural enemies. Habitat quality within the crop largely depends on the intensity of the management (e.g. pesticide applications and crop density). In enclosed farmland habitat quality for natural enemies within conventionally managed crops is generally low.

A-BL 2.7 Pollination in the UK is provided by managed honey bees and a wide range of wild insect species including bumblebees, solitary bees, hoverflies, butterflies and moths. Honey bee colonies, wild bees and hoverflies are in serious decline (Biesmeijer et al. 2006). These declines have multiple causes, but a key driver is the loss of flower-rich, semi-natural habitats providing resources for nesting and feeding (Le Féon et al. 2010). In addition, pesticides applied for intensive crop management are harmful on bees, resulting in local losses in bee diversity (Brittain et al. 2010). Oilseed rape is a mass flowering crop, providing a bounty of nectar and pollen early in the year. It therefore seems plausible to expect positive responses of flower-visiting insects to oilseed rape, and increased abundances of short-tongued social bumblebees with increasing area of oilseed rape early in the year seem to confirm this assumption (Westphal et al. 2003). The mass flowering crops however may compete with wild plants for pollinators and could alter pollinator communities with generalist species benefitting in comparison to more specialized taxa (Diekötter et al. 2010). Furthermore, mass flowering crops often only supply a short pulse of floral resources that do not provide adequate nutrition for pollinators with longer activity periods (Pleasants 1980).

A-BL 3.1 The crop rotation of the baseline farm resembles the East England arable landscape context (http://www.farmbusinesssurvey.co.uk/regional/Data.asp). Enclosed Farmland landscapes are important for the English sense of place, with lowland agricultural landscapes symbolising continuity, social stability and a productive nature (Lowenthal 1991, Firbank et al. 2011). In the East of England, in between fields of intensive food and fuel production, locally distinctive features such as hedgerows, woodlands and wetlands still remain (Natural England 2009b). Those features define the rural landscape, reflect cultural history and conserve outlines of past land use (Firbank et al. 2011).

A-BL 3.2 Some farmland habitats and associated taxa such as breeding farmland birds, butterflies and hedgerow flowers have strong cultural importance and resonance with the public (Firbank et al. 2011). Breeding farmland birds and butterflies on farmland are still in decline. Plant species richness of enclosed farmland showed some slight increase by 2007 and there is evidence that this might be attributable to the arable set-aside schemes in England (Defra 2012b). The locality of the baseline farm is of priority for farmland and migratory birds and other taxa of farmland biodiversity (Natural England 2009b). The high agricultural production of the region has however led to a decline of the connectivity of the landscape, leaving small and isolated fragments of wildlife habitat, resulting in a decline of the capacity of the landscape to support biodiversity (GOEE 2008). In winter wheat, medium to high pestizide and nitrogen applications lead to direct negative impacts on habitat quality and the dense crop is limiting nesting, shelter and growth of weeds (EEA 2007, 108 and 116). In spring barley pesticide and nitrogen applications are lower and a slightly more open structure can leave space for nesting and weeds (EEA 2007, 108 and 116). Oilseed rape poses medium to high risk to farmland biodiversity through high pestizide and nitrogen applications and a crop structure too dense to provide shelter or room for weeds (EEA 2007, 107 and 116). Oilseed rape however is a temporal feed source for bees and hoverflies (see 2.7).

Large arable farm AD maize scenario (A-MZ)

Table 10: Ecosystem service (ES) assessment for the large arable farm AD maize scenario (A-MZ)

Final and intermediate ES	**ES status**				
	Crop rotation				**Farm total**
	Winter wheat 1 + 2	**Maize**	**Spring barley**	**Oil seed rape**	
	240 ha	40 ha	20 ha	100 ha	400 ha
1. Provisioning services					
1.1 Food	**+++**	**-**	**+++**	**+++**	
1.2 Fodder		**o**			
1.3 Biomass for energy	**o**	**++**	**o**	**ooo**	
1.4 Water supply	**+/-**	**+/-**	**+**	**-**	
1.5 Wild species diversity	**+/-**	**+/-**	**+/-**	**+/-**	
1.6 Carbon	**-**	**--**	**-**	**-**	
2. Regulating services					
2.1 Hazard regulation	**-**	**---**	**--**	**+/-**	
2.2 Regulation of water quantity	**-**	**--**	**-**	**-**	
2.3 Climate regulation	**--**	**+**	**--**	**--**	
2.4 Waste breakdown	**+/- !**	**+/- !**	**+/- !**	**+/- !**	
2.5 Purification in soil	**--**	**--**	**-**	**--**	
2.6 Disease and pest regulation	**-**	**-**	**-**	**--**	
2.7 Pollination	**--**	**-**	**-**	**+/-!**	
3. Cultural services					
3.1 Environmental settings – socially valued landscapes	**+/-**	**+/-**	**+/-**	**+/-**	
3.2 Wild species diversity and wildlife habitat	**-**	**-**	**-**	**-**	

A-MZ 1.1 The introduction of 40 ha of maize into the A-BL scenario rotation results in an 80 ha reduction in spring barley cultivation and an increase in first winter wheat, resulting in almost no overall loss of grain (food) production assuming that wheat can substitute barley for e.g. animal feed.

A-MZ 1.2 The energy maize could alternatively be sold as fodder maize.

A-MZ 1.3 Maize is produced as dedicated energy crop for AD. All other crops in the rotation have potential for being used as energy feedstock as well (see A-BL 1.3).

A-MZ 1.4 Maize crops have a tendency for soil compaction (late harvesting on wet soils and sometimes followed by sowing of winter crop). The root system is poorly developed. Levels of water abstraction by maize are low to medium and the crop has a high water efficiency for Atlantic Central (SRU 2007, 42; EEA 2007, 105 and 116). Under drought conditions maize might require irrigation.

A-MZ 1.5 No changes compared to A-BL 1.5.

A-MZ 1.6 Maize shows strong negative humus reproduction rates in arable soil (Brock et al. 2013).

A-MZ 2.1 Maize as a row crop is particularly susceptible to soil erosion (Unwin 2001). Its cultivation is accompanied by long periods of uncovered soil, its root system is poorly developed and it is harvested late in the year when the likelihood of wet soil conditions and subsequent soil compaction is increased (EEA 2007, Defra 2011). Risks of erosion in maize crops are particularly high on heavy soils and slopes. Management options for enhancing soil formation and minimizing soil loss are strongly encouraged (Bardgett et al. 2011, 507).

A-MZ 2.2 There is a long vegetation-free phase in maize during which it is susceptible to strong surface runoff (Grunewald & Bastian 2013, 124). Maize stubble left over winter can be prone to overland run-off leading to soil erosion, water pollution (soil sediments and associated phosphorous) and flooding (Defra 2011).

A-MZ 2.3 The A-MZ scenario results in a 12% reduction in farm GHG emissions and a 5% reduction in acidifying gas emissions according to the LCAD tool under default settings. Thus, smaller areas of maize introduced to a rotation may result in a positive climate regulation so long as no significant quantities of food production are displaced and iLUC induced.

A-MZ 2.4 Digestate from AD plants can be applied on the arable soils. Both the nitrogen and the phosphorous of AD digestate exist in more available forms compared to parent slurry. Depending on the application technique, timing and amount applied, this could present either a benefit or a potential environmental risk (Defra 2011). If applied in excess of crop requirements, elevated losses of ammonia, nitrous oxide and nitrogenous and phosphorous compounds to water could occur (Defra 2011).

A-MZ 2.5 Nitrate leaching to water could be reduced if digestates were used effectively in place of synthetic fertilisers (Defra 2011). The risk of nutrient inputs to ground and surface water by maize is medium to high (EEA 2007, 105).

A-MZ 2.6 The impact of maize cultivation on biocontrol depends on the percentage cover of maize in the landscape. If maize planting results in lower landscape diversity, the supply of biocontrol services to arable fields will be reduced (Landis et al. 2008). In comparison to other crops such as oilseed rape or cereals, maize hosts the lowest number of weed species (Waldhardt et al. 2011) and thus provides little alternative resources such as shelter or food for biocontrol agents. Maize stubbles can harbor Fusarium fungi; an important pathogen of wheat which could potentially compromise the crop rotation and expected benefits (Defra 2011).

A-MZ 2.7 Alternative energy crops to maize such as *Silphium perfoliatum* or wild plant mixtures could provide pollen and nectar resources for pollinators and would increase habitat diversity.

A-MZ 3.1 Depending on its percentage cover in the landscape, maize might alter the visual landscape character because due to the height of maize crops in the summer, sightlines are limited (Grunewald & Bastian 2013, 126).

A-MZ 3.2 The addition of an annual biofuel crop such as oilseed rape to an existing arable crop rotation is unlikely to make a difference to biodiversity due to comparable management and inputs (fertiliser, pesticides) requirements (Berry & Paterson 2009). Maize production could however negatively impact on biodiversity because it is intolerant of competition during early growth stages and requires higher inputs of herbicides than other arable crops, and tends to support fewer weed species below the canopy (Defra 2011). Evidence for reduced biodiversity under conventional maize cultivation is available from the FSA GM trials which showed that fields sown with conventional maize were the poorest in plant and animal life: Reduced weed diversity is related to reduced diversity of invertebrate taxa, including both soil dwelling and aerial species (Brooks et al. 2003, Haughton et al. 2003). From a landscape perspective, however, in areas of very narrow crop rotations, maize can widen the crop rotation with potentially positive effects on habitat function and species richness, as long as the percentage cover of maize in the area stays well below 40% (Wiehe et al. 2009, Waldhardt et al. 2011). The response of biodiversity to maize production is taxon specific and depends on percentage cover as well as on aggregation of the fields in the landscape (Gevers et al. 2011).

Large arable farm AD maize monoculture scenario (A-MZ100)

Table 11: Ecosystem service (ES) assessment for the large arable farm AD maize monoculture scenario (A-MZ100)

Final and intermediate ES	ES status				
	Crop rotation				Farm total
	Winter wheat 1 + 2	Maize	Spring barley	Oil seed rape	
	0 ha	400 ha	0 ha	0 ha	400 ha
1. Provisioning services					
1.1 Food		---			
1.2 Fodder		--- o			
1.3 Biomass for energy		++			
1.4 Water supply		+/-			
1.5 Wild species diversity		+/-			
1.6 Carbon		--			
2. Regulating services					
2.1 Hazard regulation		---			
2.2 Regulation of water quantity		--			
2.3 Climate regulation		---			
2.4 Waste breakdown		+/- !			
2.5 Purification in soil		--			
2.6 Disease and pest regulation		-			
2.7 Pollination		-			
3. Cultural services					
3.1 Environmental settings – socially valued landscapes		--			
3.2 Wild species diversity and wildlife habitat		-			

A-MZ100 1.1 The maize monoculture scenario is an extreme example but indicates what can happen when large areas of maize are cultivated as a feedstock for AD units. The farm fundamentally changes from a food- to an energy- producing farm. Unlike the A-MZ scenario where maize can be accommodated within crop rotations without large food production displacement, all food production is displaced elsewhere in this scenario. Whether such a reduction would have impacts on national food security depends on the scale of production of non-food crops on arable land in the UK. AEA/ADAS (2011) calculated that there is sufficient land to provide 100,000 ha of land for AD feedstocks without impacting on UK food and feed wheat demands. The RELU anaerobic Digestion Project suggested that AD is likely to have minimal impacts on food production in the UK (Defra 2011, Jones 2010).

A-MZ100 1.2 The energy maize could alternatively be sold as fodder maize.

A-MZ100 1.3 Maize is produced as dedicated energy crop for AD.

A-MZ100 1.4 Maize crops have a tendency for soil compaction (late harvesting on wet soils and sometimes followed by sowing of winter crop). The root system is poorly developed. Levels of water abstraction by maize are low to medium and the crop has a high water efficiency for Atlantic Central (SRU 2007, 42; EEA 2007, 105 and 116). Under drought conditions maize might require irrigation.

A-MZ100 1.5 No changes compared to A-BL 1.5.

A-MZ100 1.6 Maize shows strong negative humus reproduction rates in arable soil (Brock et al. 2013).

A-MZ100 2.1 Maize as a row crop is particularly susceptible to soil erosion (Unwin 2001). Its cultivation is accompanied by long periods of uncovered soil, its root system is poorly developed and it is harvested late in the year when the likelihood of wet soil conditions and subsequent soil compaction is increased (EEA 2007, Defra 2011). Risks of erosion in maize crops are particularly high on heavy soils and slopes. Management options for enhancing soil formation and minimizing soil loss are strongly encouraged (Bardgett et al. 2011, 507).

A-MZ100 2.2 There is a long vegetation-free phase in maize during which it is susceptible to strong surface runoff (Grunewald & Bastian 2013, 124). Maize stubble left over winter can be prone to overland run-off leading to soil erosion, water pollution (soil sediments and associated phosphorous) and flooding (Defra 2011).

A-MZ100 2.3 According to the LCAD tool with default setting and considering iLUC, the A-MZ100 scenario results in an 83% increase in lifecycle global warming burden, an 80% increase in lifecycle eutrophication burden but a 32% reduction in acidification burden owing to displaced electricity generation. Overall, this scenario has a strongly negative impact on both climate and water quality regulation.

A-MZ100 2.4 Digestate from AD plants can be applied on the arable soils. Both the nitrogen and the phosphorous of AD digestate exist in more available forms compared to parent slurry. Depending on the application technique, timing and amount applied, this could present either a benefit or a potential environmental risk (Defra 2011). If applied in excess of crop requirements, elevated losses of ammonia, nitrous oxide and nitrogenous and phosphorous compounds to water could occur (Defra 2011).

A-MZ100 2.5 Nitrate leaching to water could be reduced if digestates were used effectively in place of synthetic fertilisers (Defra 2011). The risk of nutrient inputs to ground and surface water by maize is medium to high (EEA 2007, 105).

A-MZ100 2.6 The impact of maize cultivation on biocontrol depends on the percentage cover of maize in the landscape. If maize planting results in lower landscape diversity, the supply of biocontrol services to arable fields will be reduced (Landis et al. 2008). In comparison to other crops such as oilseed rape or cereals, maize hosts the lowest number of weed species (Waldhardt et al. 2011) and thus provides little alternative resources such as shelter or food for biocontrol agents. Maize stubbles can harbor Fusarium fungi; an important pathogen of wheat which could potentially compromise the crop rotation and expected benefits (Defra 2011).

A-MZ100 2.7 Alternative energy crops to maize such as *Silphium perfoliatum* or wild plant mixtures could provide pollen and nectar resources for pollinators and would increase habitat diversity.

A-MZ100 3.1 Depending on its percentage cover in the landscape, maize might alter the visual landscape character because due to the height of maize crops in the summer, sightlines are limited (Grunewald & Bastian 2013, 126).

A-MZ100 3.2 The addition of an annual biofuel crop such as oilseed rape to an existing arable crop rotation is unlikely to make a difference to biodiversity due to comparable management and inputs (fertiliser, pesticides) requirements (Berry & Paterson 2009). Maize production could however negatively impact on biodiversity because it is intolerant of competition during early growth stages and requires higher inputs of herbicides than other arable crops, and tends to support fewer weed species below the canopy (Defra 2011). Evidence for reduced biodiversity under conventional maize cultivation is available from the FSA GM trials which showed that fields sown with conventional maize were the poorest in plant and animal life: Reduced weed diversity is related to reduced diversity of invertebrate taxa, including both soil dwelling and aerial species (Brooks et al. 2003, Haughton et al. 2003). From a landscape perspective, however, in areas of very narrow crop rotations, maize can widen the crop rotation with potentially positive effects on habitat function and species richness, as long as the percentage cover of maize in the area stays well below 40% (Wiehe et al. 2009, Waldhardt et al. 2011). The response of biodiversity to maize production is taxon specific and depends on percentage cover as well as on aggregation of the fields in the landscape (Gevers et al. 2011).

Large arable farm AD grass scenario (A-G)

Table 12: Ecosystem service (ES) assessment for the large arable farm AD grass scenario (A-G)

Final and intermediate ES	ES status				
	Crop rotation				
	Winter wheat 1 + 2	Rye grass	Spring barley	Oil seed rape	Farm total
	180 ha	40 ha	90 ha	90 ha	400 ha
1. Provisioning services					
1.1 Food	+++	--	+++	+++	
1.2 Fodder		o			
1.3 Biomass for energy	o	+	o	ooo	
1.4 Water supply	+/-	+/-	+	-	
1.5 Wild species diversity	+/-	+/-	+/-	+/-	
1.6 Carbon sequestration	-	+/- o	-	-	
2. Regulating services					
2.1 Hazard regulation	-	+/- o	--	+/-	
2.2 Regulation of water quantity	-	-	-	-	
2.3 Climate regulation	--	-	--	--	
2.4 Waste breakdown	+/- !	+/- !	+/- !	+/- !	
2.5 Purification in soil	--	-	-	--	
2.6 Disease and pest regulation	-	-	-	--	
2.7 Pollination	--	- o	-	+/-!	
3. Cultural services					
3.1 Environmental settings – socially valued landscapes	+/-	+	+/-	+/-	
3.2 Wild species diversity and wildlife habitat	-	-	-	-	

A-G 1.1 The conversion of 10% of the farm area to ryegrass production as an AD feedstock results in a 10% reduction in food production. Whether such a reduction would have impacts on the national food security depends on the scale of production of non-food crops on arable land in the UK. AEA/ADAS (2011) calculated that there is sufficient land to provide 100,000 ha of land for AD feedstocks without impacting on UK food and feed wheat demands. The RELU anaerobic Digestion Project suggested that AD is likely to have minimal impacts on food production in the UK (Defra 2011, Jones 2010).

A-G 1.2 Perennial ryegrass is highly digestible for all classes of ruminant animals and is valuable as hay, silage, and pasture (Cool & Hannaway 2004).

A-G 1.3 Perennial ryegrass grows best on fertile, well-drained soils but it does not generally tolerate drought or extended periods of extreme temperatures well. It does well in fertile summer-irrigated or sub-irrigated soils and is not very persistent or productive on lower fertility summer-dry soils. It is high yielding under good environmental conditions and proper fertilization (Cool & Hannaway 2004). Grass-growing days are <200 days/ year in the dry lowlands of eastern England (Hopkins 2008) and thus yields might be below the national average. All other crops in the rotation have potential for being used as energy feedstock as well (see A-BL 1.3).

A-G 1.4 Evapotranspiration of permanent grass is comparable to wheat but percolation rates of permanent grass are higher (Stephens et al. 2001). Ryegrass is vulnerable to drought conditions.

A-G 1.5 No changes compared to A-BL 1.5.

A-G 1.6 Improved grassland management including multiple harvests and reseeding can deplete soil carbon stocks. The conversion of the arable crop rotation to a non-permanent grassland crop might not lead to an improvement of the soil carbon content. Reseeding of grassland is recommended in order to improve the grass vigour and growth and reseeding frequencies range from every 2 to 3 years up to every 8 years. Direct sowing is the most common method of establishment and for this the existing sward is ploughed in and allowed to rot for a few weeks, harrowed, fertilized and rolled before sowing (Smyth et al. 2009). Direct drilling, which is a method of seeding without ploughing, might be an option for reducing carbon loss from the soil.

A-G 2.1 The permanent vegetation cover reduces the risk of wind or water erosion. An additional reduction of erosion hazard could be provided by direct drilling for reseeding because no ploughing of the soil is required and there is no vegetation-free phase involved in the crop management.

A-G 2.2 Management of ryegrass as a permanent grassland could reduce surface run-off and improve water retention in comparison to arable crops (Stephens et al. 2001). However, fertilizer application rates are high.

A-G 2.3 When displaced food production and associated iLUC is considered, with all other parameters set at default values, the A-G scenario results in small increases in lifecycle GHG, eutrophying gas and acidifying gas emissions, thus providing a disservice to climate and water regulation.

A-G 2.4 Perennial ryegrass can be fertilized with digestate from AD plants. Application of liquid digestate fraction (N- and K-rich) is recommended in early spring (Möller et al. 2009).

A-G 2.5 Pesticide application on perennial ryegrass should be significantly lower than on winter wheat. The amount of fertilizer necessary depends on the soil conditions and the number of harvests per year. Digestate is an alternative to mineral fertilization but application rates should be in accordance to nutrient uptake of the grass. Management is still highly intensive and risk of nutrient leaching is given.

A-G 2.6 In contrast to seminatural grassland elements and grassy field banks, improved grasslands do not support a high amount of natural biocontrol agents. Lolium perenne might serve as a secondary winter host for the aphid *Rhopalosiphum padi* (Leather & Dixon 1982).

A-G 2.7 Number of flowering plant species is very low on conventional improved grasslands and number of insect pollinators is also low, reflecting the poor provision of food resources (Power & Stout 2011). An increased abundance of flowering plants such as white clover could support pollinators and thus pollination services in agricultural landscapes (Power & Stout 2011). Grass-clover mixtures are among the dedicated crops recommended for AD in Germany (FNR 2012b). The efficiency of anaerobic digestion can be considerably improved in mixed feedstock such as that of grass with legumes because it reduces indigestible material and increases in digestibility of the feedstock (Smyth et al. 2009).

A-G 3.1 The conversion of wheat fields to grassland would help breaking the landscape wide dominance of wheat and help diversifying the visual character of the landscape composition.

A-G 3.2 Intensive management practices in improved grasslands include the application of inorganic fertilizers, reseeding, improved drainage and the replacement of hay with silage cutting, resulting in floristically species poor and structurally uniform habitats (Vickery et al. 2001). For this reason they typically have a low biodiversity value, not only for plants, but also for invertebrates and birds (Woodcock et al. 2009).

Large arable farm AD Miscanthus scenario (A-M)

Table 13: Ecosystem service (ES) assessment for the large arable farm AD Miscanthus scenario (A-M)

Final and intermediate ES	ES status				
	Crop rotation				
	Winter wheat 1 + 2	Miscanthus	Spring barley	Oil seed rape	Farm total
	180 ha	40 ha	90 ha	90 ha	400 ha
1. Provisioning services					
1.1 Food	+++	-	+++	+++	
1.2 Fodder					NA
1.3 Biomass for energy	o	++	o	ooo	
1.4 Water supply	+/-	-	+	-	
1.5 Wild species diversity	+/-	+/-	+/-	+/-	
1.6 Carbon sequestration	-	++	-	-	
2. Regulating services					
2.1 Hazard regulation	-	++	--	+/-	
2.2 Regulation of water quantity	-	++	-	-	
2.3 Climate regulation	--	++	--	--	
2.4 Waste breakdown	o	-	o	o	
2.5 Purification in soil	--	+	-	--	
2.6 Disease and pest regulation	-	+/-	-	--	
2.7 Pollination	--	+/-	-	+/- !	
3. Cultural services					
3.1 Environmental settings – socially valued landscapes	+/-	+/-	+/-	+/-	
3.2 Wild species diversity and wildlife habitat	-	+/-	-	-	

A-M 1.1 The conversion of 10% of the farm area to Miscanthus as results in 10% reduction in grain output. Whether such a reduction would have impacts on the national food security depends on the scale of production of non-food crops on arable land in the UK. AEA/ADAS (2011) calculated that there is sufficient land to provide 100,000 ha of land for AD feedstocks without impacting on UK food and feed wheat demands. The RELU anaerobic Digestion Project suggested that AD is likely to have minimal impacts on food production in the UK (Defra 2011, Jones 2010).

A-M 1.2 Miscanthus cannot be used as fodder but there are other alternative uses to biomass for energy such as bedding or feedstock for building material.

A-M 1.3 Miscanthus is the preferred lignocellulosic biomass crop in the dryer eastern climate of the UK (Bauen et al. 2010). All other crops in the rotation have potential for being used as energy feedstock as well (see A-BL 1.3).

A-M 1.4 Miscanthus has a greater evapotranspiration rate than arable crops or permanent grassland due to a combination of higher growth rates, high transpiration rates, longer seasonal growth and increased rooting depth and complexity (Rowe et al. 2009). Water availability should therefore be an important factor when considering the location for planting Miscanthus, with areas of adequate rainfall being most suitable (McKervey et al. 2008). Due to the high water requirements of Miscanthus and the loss of percolation detectable reductions in aquifer recharge and stream flow might occur at the sub-catchment scale, if the land cover of miscanthus is too high to be compensated by conventional crops (Stephens et al. 2001). At national level, Stephens et al. (2001) state, that the establishment of 100,000 ha of energy crops (Miscanthus and or SRC willow) would result in a reduction of the total freshwater resource equivalent to 0.2% of the national freshwater resource or 12% of annual freshwater abstractions.

A-M 1.5 No changes compared to A-BL 1.5.

A-M 1.6 There is a general consensus that the conversion of arable land to Miscanthus will result in an increase in carbon sequestration (Rowe et al. 2009).

A-M 2.1 Miscanthus is a permanent crop which can remain in situ for >10-15 years. Risk of soil erosion by wind or water is therefore low for Miscanthus for Atlantic Central (EEA 2007, 110, 116).

A-M 2.2 It has been proposed that in some areas the high water use of Miscanthus could be utilized in flood management to reduce flooding in risk areas (Rowe et al. 2009). The impact on water quantity would be due to the combined effect of soil drying, decreased runoff and increase penetration associated with these plantations (Rowe et al. 2009).

A-M 2.3 The A-M scenario results in a 50% reduction in farm GHG emissions, even when iLUC for displaced food production is taken into account. Other authors have reported strong carbon and energy balances for miscanthus from an ecosystem services perspective (e.g. Rowe et al. 2009).

A-M 2.4 Waste application on Miscanthus might not be advisable due to its low fertilizer requirements. In an Irish study, spread of distillery effluent resulted in excessive PO_4^{3-} in the plot groundwater which was likely due to high background soil P, soil characteristics, and the occurrence of soil macropore flow (Galbally et al. 2012).

A-M 2.5 There is a low risk of nutrient or pesticide leaching to ground and surface water by Miscanthus for Atlantic Central (EEA 2007, 114). The nutrient requirements of the crop are low and no fertilization is required because the plants relocate nutrients into the rhizome before harvest. Miscanthus crops require weed control, particularly during the first two years of crop establishment, but few diseases or pests have been found in European crops to date (McKervey et al. 2008). The use of Miscanthus for phytoremediation is little studied.

A-M 2.6 At present, the incidence of disease on the growing Miscanthus crop is negligible because there is limited production in the UK and Europe. However, it has been suggested that barley yellow dwarf virus, Fusarium and *Leptosphaeria sp* (Miscanthus blight) could pose a potential threat in the future with increased production of Miscanthus. Miscanthus has the potential to act as an intermediate host for the aphids between their infestation of summer wheat and barley crops and subsequent infection of winter grasses and cereals (McKervey et al. 2008). There is also a potential for Miscanthus to act as a refuge or reservoir for western corn rootworm *Diabrotica virgifera virgifera* LeConte (Spencer & Raghu 2009). The importance of Miscanthus for natural biocontrol agents such as epigeic predatory arthropods and parasitoids is still little understood. Stanley & Stout (2013), who found larval-predatory wasps colonizing the trap nests in Miscanthus, suggested that Miscanthus could perhaps be a reservoir for those biocontrol agents.

A-M 2.7 In landscapes dominated by arable farming, land-use change from conventional crops to Miscanthus on a small scale may result in increases in some pollinator groups, especially solitary bees (Stanley & Stout 2013). Miscanthus may support a diverse and abundant within-field plant community that can be beneficial for flower visiting insects; in addition, Miscanthus might provide nesting opportunities due to its low-disturbance, perennial nature and potential nest sites offered by dead stems left in the field after harvesting (Stanley & Stout 2013). If, however, Miscanthus fields were weed-free at all times, e.g. due to a very dense crop cover, their positive effects on pollinating insects would be diminished.

A-M 3.1 Miscanthus remains in situ for >10-15 years and can grow up to 4 m in height in the UK. This may create a visual impact on the rural landscape (Rowe et al. 2009). Therefore, establishment of Miscanthus plantations should take account of landscape aesthetics and public foot path access, as well as local archaeology (McKervey et al. 2008).

A-M 3.2 The perennial nature and the low pesticide and nitrogen applications to Miscanthus suggest positive impacts on biodiversity within agricultural settings (EEA 2007, 110, 116). A couple of studies from the UK and Ireland report positive effects on birds, invertebrates and plants but our understanding of the potential effects of Miscanthus on biodiversity is limited to studies of plantations during the establishment phase, which is characterized by patchy crop cover (Rowe et al. 2009, Bourke et al. in press). Mature high yielding monoculture plantings of Miscanthus may offer very little by way of habitat to local flora and fauna (Berry et al. 2011). Therefore, if Miscanthus fields had a closed canopy and were kept weed-free at all times, their invertebrate populations were bound to resemble that of arable crops (McKervey et al. 2008). There have been some concerns whether Miscanthus, as an introduced species, might be an invasive plant but this is not a problem as long as sterile hybrid varieties are used (McKervey et al. 2008).

Biofuel scenarios (A-Eth and A-Biod)

Full ecosystem services assessment is not performed for these scenarios because they do not involve any direct land use or management changes on the A-BL farm. Results of the LCAD tool can be used to determine the net GHG and water quality effects. Food production is displaced elsewhere, with negative consequences for food provisioning.

6. References

AEA/ADAS (2011) Implementation of AD in England & Wales: Balancing optimal outputs with minimal environmental impacts - Impact of using purpose grown crops. Report to Defra, AEAT/ENV/R/3220

Bardgett RD, Campbell CD, Emmet BA, et al. (2011) Supporting services. In: The UK National Ecosystem Assessment Technical Report. UK National Ecosystem Assessment, UNEP-WCMC, Cambridge, 499-534.

Bauen AW, Dunnett AJ, Richter GM, Dailey AG, et al. (2010) Modelling supply and demand of bioenergy from short rotation coppice and Miscanthus in the UK. Bioresource Technology, 101, 8132–8143.

Benton TG, Vickery JA, Wilson JD (2003) Farmland biodiversity: is habitat heterogeneity the key? Trends in Ecology & Evolution, 18, 182–188.

Berry P, Paterson JS (2009) Energy mitigation, adaptation and biodiversity: synergies and antagonisms. IOP Conf.Series: Earth and Environmental Science, 8, 012023, doi:10.1088/1755-1315/8/1/012023

Berry P, Hopkins J, et al. (2011) Status and Changes in the UK Ecosystems and their Services to Society: England. In: The UK National Ecosystem Assessment Technical Report. UK National Ecosystem Assessment, UNEP-WCMC, Cambridge, 693-774.

Biesmeijer JC, Roberts SPM, Reemer M, Ohlemuller R, et al. (2006) Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science, 313, 351–354.

Boatman ND, Parry HR, et al. (2007) Impacts of Agricultural Change on Farmland Biodiversity in the UK. In: Hester RE, Harrison RM (eds) *Biodiversity Under Threat*. Issues in Environmental Science and Technology, No. 25, 1-32.

Boulamanti AK, Maglio SD, Giuntoli J, Agostini A (2013) Influence of different practices on biogas sustainability. Biomass and Bioenergy, 53, 149-161.

Bourke D, Stanley D, O'Rourke E, Thompson R, et al. (in press) Response of farmland biodiversity to the introduction of bioenergy crops: effects of local factors and surrounding landscape context. GCB Bioenergy.

Brittain CA, Vighi M, Bommarco R, Settele J, Potts SG (2010) Impacts of a pesticide on pollinator species richness at different spatial scales. Basic and Applied Ecology, 11, 106–115.

Brooks DR, Bohan DA, Champion GT, Haughton AJ, et al. (2003) Invertebrate responses to the management of genetically modified herbicide-tolerant and conventional spring crops. I. Soil-surface-active invertebrates. Philosophical Transactions of the Royal Society of London B, 358, 1847–1862.

Brock C, Bernert S, Willms M, Knebl L, Leithold G (2013) Estimating humus reproduction of bioenergy crops. Journal für Kulturpflanzen, 65, 227-235.

Church A, Burgess J, Ravenscroft N, et al. (2011) Cultural Services. In: The UK National Ecosystem Assessment Technical Report. UK National Ecosystem Assessment, UNEP-WCMC, Cambridge, 633-692.

Cool M, Hannaway DB (2004) Forage Fact Sheet: Perennial Ryegrass. http://forages.oregonstate.edu/php/fact_sheet_print_grass.php?SpecID

Countryside Survey (2007) UK Results from 2007. CHAPTER 3 Enclosed Farmland: Arable and Horticulture and Improved Grassland Broad Habitats. pp. 30-38.

Dale A, Ferris C (2011) The effect of applying cattle slurry within rotational grazing systems using trailing-shoe technology on dairy cow and sward performance. End of Project Report to AgriSearch in relation to contract numbers D-35-07 and D-39-08. 50 pp. http://www.agrisearch.org/attachments/article/91/Technical%20Report%20-%20Effect%20of%20applying%20slurry%20within%20grazing%20on%20cow%20performance%20%28D-35-07%20D-39-08%29.pdf

DECC (2012) UK Bioenergy Strategy. 86 pp. https://www.gov.uk/government/organisations/department-of-energy-climate-change

Defra (2011) Wider Impacts of Anaerobic Digestion: Agronomic and Environmental Costs and Benefits. Evidence summary and commentary. 46 pp.

Defra (2012a) Anaerobic Digestion Strategy and Action Plan. Annual Report on Progress 2011/12. www.defra.gov.uk/publications/

Defra (2012b) A strategy for England's wildlife and ecosystem services. Biodiversity 2020 Indicators: 2012 Assessment. http://www.Defra.gov.uk/statistics/environment/biodiversity/england-biodiversity-indicators/

Defra (2013) Agriculture in the United Kingdom 2012. https://www.gov.uk/government/publications/agriculture-in-the-united-kingdom-2012

Diekötter T, Kadoya T, Peter F, Wolters V, Jauker F (2010) Oilseed rape crops distort plant-pollinator interactions. Journal of Applied Ecology, 47, 209–214.

EEA (European Environment Agency; 2007) Estimating the environmentally compatible bioenergy potential from agriculture. EEA Technical report No 12/2007.

Environment & Heritage Service (2005) Natural Heritage. Grasslands. NH004, http://www.doeni.gov.uk/niea/nh004.pdf

Firbank L, Bradbury RB, McCracken DI, Stoate C (2013) Delivering multiple ecosystem services from Enclosed Farmland in the UK. Agriculture, Ecosystems and Environment 166, 65– 75.

Firbank L, Bradbury RB, McCracken DI, Stoate C, et al. (2011) Enclosed farmland. In: The UK National Ecosystem Assessment Technical Report. UK National Ecosystem Assessment, UNEP-WCMC, Cambridge, 197-238.

FNR (Fachagentur für Nachwachsende Rohstoffe e.V.; 2012a) Guide to Biogas -From production to use. 232 pp.

FNR (Fachagentur für Nachwachsende Rohstoffe e.V; 2012b) Energiepflanzen für Biogasanlagen. Bayern. 116 pp.

Galbally P, Fagan C, Ryan D, Finnan J, et al. (2012) Biosolids and distillery effluent amendment to Irish Miscanthus × giganteus plantations: Impacts on groundwater and soil. Journal of Environmental Quality, 41, 114-123.

Gevers J, Hoye TT, Topping CJ, Glemnitz M, Schroder B (2011) Biodiversity and the mitigation of climate change through bioenergy: impacts of increased maize cultivation on farmland wildlife. Global Change Biology Bioenergy, 3, 472–482.

Gloyna K, Thieme T, Zellner M (2011) Miscanthus, a host for larvae of a European population of Diabrotica v. virgifera. Journal of Applied Entomology, 135, 780-785.

GOEE (Government Office for the East of England; 2008) East of England Plan: The Regional Spatial Strategy for the East of England (online) available at: www.goeast. gov.uk/

Grunewald K, Bastian O (2013) Ökosystemdienstleistungen, Springer, Spektrum.

Härtel S, Danner N, Steffan-Dewenter I (2010) Resource use of maize pollen by honeybees in differentially structured landscapes. Proceedings of the 4th European Conference of Apidology, EurBee, (Ankara, Turkey), 84.

Haughton AJ, Champion GT, Hawes C, et al. (2003) Invertebrate responses to the management of genetically modified herbicide-tolerant and conventional spring crops. II. Within-field epigeal and aerial arthropods. Philosophical Transactions of the Royal Society of London B, 358, 1863–1877.

Hopkins A (2008) Country Pasture/Forage Resource Profiles. UNITED KINGDOM. FAO, 26 pp., http://www.fao.org/ag/agp/AGPC/doc/Counprof/PDF%20files/UnitedKingdom.pdf

Howard DC, Watkins JW, Clarke RT, Barnett CL, Stark GJ (2003) Estimating the extent and change in Broad Habitats in Great Britain. J. Environ. Manage. 67, 219–227.

Howard DC, Burgess PJ, Butler SJ, Carver SJ, et al. (2012) Energyscapes: Linking the energy system and ecosystem services in real landscapes. Biomass and Bioenergy 55, 17-26.

Johnston AE, Poulton PR, Coleman K (2009) Soil organic matter: its importance in sustainable agriculture and carbon dioxide fluxes. Advances in Agronomy, 101, 1–57.

Jones P (2010) Work Package 7: Modelling the Commercial Profitability of AD Energy Production at the Farm Level within Arable and Dairy Systems, RELU report.

Landis DA, Wratten SD, Gurr GM (2000) Habitat management to conserve natural enemies of arthropod pests in agriculture. Annual Review of Entomology, 45, 175–201.

Landis DA, Gardiner MM, van der Werf W, Swinton SM (2008) Increasing corn for biofuel production reduces biocontrol services in agricultural landscapes. PNAS, 105, 20552–20557.

Leather SR, Dixon AFG (1982) Secondary host preferences and reproductive activity of the bird cherry-oat aphid, Rhopalosiphum padi. Annals of Applied Biology, 101, 219–228.

Le Féon V, Schermann-Legionnet A, Delettre Y, Aviron S, et al. (2010) Intensification of agriculture, landscape composition and wild bee communities: A large scale study in four European countries. Agriculture Ecosystems & Environment, 137, 143–150.

Lowenthal D (1991) British national identity and the English landscape. Rural History, 2, 205–230.

Lupp G, Albrecht J, Darbi M, Bastian O (2011) Ecosystem services in energy crop production – a concept for regulatory measures in spatial planning? Journal of Landscape Ecology, 4, 49-66.

Mace GM, Bateman I, et al. (2011) Conceptual framework and methodology. In: The UK National Ecosystem Assessment Technical Report. UK National Ecosystem Assessment, UNEP-WCMC, Cambridge, 11- 26.

Maskell LC, Crowe A, Dunbar MJ, Emmett B, et al. (2013) Exploring the ecological constraints to multiple ecosystem service delivery and biodiversity. Journal of Applied Ecology, 50, 561–571.

Masuda T, Goldsmith PD (2009) World Soybean Production: Area Harvested, Yield, and Long-Term Projections. International Food and Agribusiness Management Review, 12, 143-162.

McKervey Z, Woods VB, Easson DL (2008) Miscanthus as an energy crop and its potential for Northern Ireland. A review of current knowledge. AFBI Occasional publication No. 8, 80 pp.

Möller K, Schulz R, Müller T (2009) Mit Gärresten richtig Düngen. Aktuelle Informationen für Berater. Institut für Pflanzenernährung, Universität Hohenheim, 56 pp.

Natural England (2009a) Experiencing landscapes: capturing the cultural services and experiential qualities of landscape. Natural England Report NECR0124. Natural England, Sheffield.

Natural England (2009b) Investing in the East of England's natural assets: state, value and vision. http://publications.naturalengland.org.uk/publication/54001

Obersteiner M, Böttcher A, Yamagata Y (2010) Terrestrial ecosystem management for climate change mitigation. Current Opinion in Environmental Sustainability, 2, 271–276.

Pleasants JM (1980) Competition for bumblebee pollinators in Rocky Mountain plant communities. Ecology, 61, 1446–59.

Potts SG, Woodcock BA, Roberts SPM, et al. (2009) Enhancing pollinator biodiversity in intensive grasslands. Journal of Applied Ecology, 46, 369–379.

Power AG (2010) Ecosystem services and agriculture: tradeoffs and synergies. Philosophical Transactions of the Royal Society of London B, 365, 2959-2971.

Power EF, Stout JC (2011) Organic dairy farming: impacts on insect–flower interaction networks and pollination. Journal of Applied Ecology, 48, 561–569.

Prasifka JR, Bradshaw JD, Gray ME (2012) Potential biomass reductions to Miscanthus x giganteus by stem-boring caterpillars. Environmental Entomology, 41, 865-871.

Quinton JN, Govers G, Van Oost KV, Bardgett RD (2010) The impact of agricultural soil erosion on biogeochemical sampling. Nature Geoscience, 3, 311–314.

Rowe RL, Street NR, Taylor G (2009) Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK. Renewable and Sustainable Energy Reviews, 13, 271–290.

Smith P, Ashmore M, Black H, Burgess P, et al. (2011) Regulating Services. In: The UK National Ecosystem Assessment Technical Report. UK National Ecosystem Assessment, UNEP-WCMC, Cambridge, 535-596.

Smyth BM, Murphy JD, O'Brien CM (2009) What is the energy balance of grass biomethane in Ireland and other temperate northern European climates? Renewable and Sustainable Energy Reviews, 13, 2349–2360.

Spencer JL, Raghu S (2009) Refuge or Reservoir? The Potential Impacts of the Biofuel Crop Miscanthus x giganteus on a Major Pest of Maize. PLoS ONE 4(12): e8336. doi:10.1371/journal.pone.0008336

SRU (Sachverständigenrat für Umweltfragen; 2007) Klimaschutz durch Biomasse: Sondergutachten. Hausdruck.

Stanley DA, Stout JC (2013) Quantifying the impacts of bioenergy crops on pollinating insect abundance and diversity: a field-scale evaluation reveals taxon-specific responses. Journal of Applied Ecology, 50, 335–344.

Stephens W, Hess T, Knox J (2001) Review of the effects of energy crops on hydrology, NF0416, Report to MAFF by Institute of Water and the Environment, Cranfield University, Silsoe.

Thumim J, White V (2007) Devon Miscanthus and Woodfuels Opportunities Statement. Centre for Sustainable Energy, Bristol, 11 pp. http://www.cse.org.uk/pdf/pub1087.pdf

Tscharntke T, Klein AM, Kruess A, Steffan-Dewenter I, Thies C (2005) Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. Ecology Letters, 8, 857–874.

Unwin RJ (2001) New Initiatives to Control Soil Erosion In England. In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds). Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory. pp. 426-430.

Verheijen F, Jones R, Rickson R, Smith C (2009) Tolerable versus actual soil erosion rates in Europe. Earth-Science Reviews, 94, 23–38.

Vickery JA, Tallowin JR, Feber RE, Asteraki EJ, et al. (2001) The management of lowland neutral grasslands in Britain: effects of agricultural practices on birds and their food resources. Journal of Applied Ecology, 38, 647–664.

Waldhardt R, Otte A, Simmering S, Ginzler O (2011) Biogas gegen Biodiversität? DLG-Mitteilungen, 3/2011, 20-23.

Westphal C, Steffan-Dewenter I, Tscharntke T (2003) Mass flowering crops enhance pollinator densities at a landscape scale. Ecology Letters, 6, 961–965.

Wiehe J, von Ruschkowski E, Rode M et al. (2009) Auswirkungen des Energiepflanzenanbaus auf die Landschaft. Naturschutz und Landschaftsplanung, 41, 107–113.

Woodcock BA, Potts SG, Tscheulin T, Pilgrim E, et al. (2009) Responses of invertebrate trophic level, feeding guild and body size to the management of improved grassland field margins. Journal of Applied Ecology, 46, 920–929.

Zhang W, Ricketts TH, Kremen C, Carney K, Swinton SM (2007) Ecosystem services and dis-services to agriculture. Ecological Economics, 64, 253–260.

Zimmermann J, Dauber J, Jones MB (2012) Soil carbon sequestration during the establishment phase of Miscanthus x giganteus: a regional-scale study on commercial farms using 13C natural abundance. GCB Bioenergy, 4, 453–461.